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ABSTRACT

A ten-part questionnaire was administered to deans and directors of all engineering programs of the University of California, California State University, University of the Pacific, and Loyola Marymount University. This seven-part report is based on responses obtained by the questionnaires. The first part describes differing opinions about shortages or surpluses of supply of engineers, computer scientists, and other technologically skilled workers. The second identifies engineering and computer science programs in California colleges/universities, reports their enrollments, and discusses major problems regarding enrollments. The third describes the shortage of engineering and computer science faculty nationally and in California, with particular emphasis on the California State University and the University of California. The fourth identifies pressing problems of equipment and facilities, including not merely deferred maintenance and replacements but also the lack of technologically-advanced equipment already used in industry. The fifth points to sources of inadequate preparation of students, both nationally and in California. The sixth notes incentives that industry are providing universities and that states are providing to their public universities to develop technological expertise. And the seventh summarizes the report by pointing to the educational and financial implications of issues discussed in previous sections for educational policy makers in California. (Author/JN)

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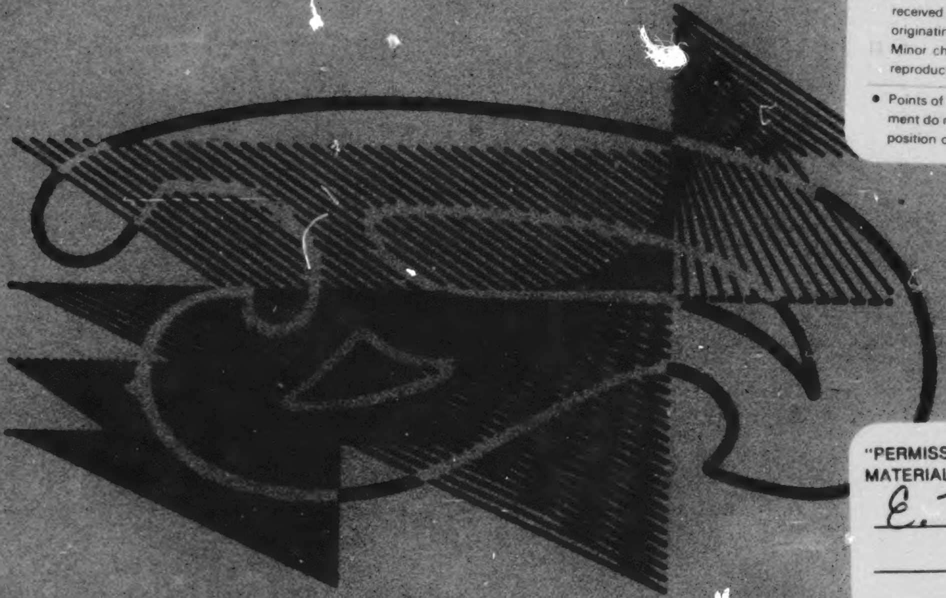

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The Commission consists of 15 members. Nine represent the general public, with three each appointed by the Speaker of the Assembly, the Senate Rules Committee, and the Governor. The other six represent the major educational systems of the State.

The Commission holds regular public meetings throughout the year at which it takes action on staff studies and adopts positions on legislative proposals affecting postsecondary education. Further information about the Commission, its meetings, its staff, and its other publications may be obtained from the Commission offices at 1020 Twelfth Street, Sacramento, California 95814; telephone (916) 445-7933.

ENGINEERING AND COMPUTER SCIENCE EDUCATION IN CALIFORNIA PUBLIC HIGHER EDUCATION

CALIFORNIA POSTSECONDARY EDUCATION COMMISSION
1020 Twelfth Street, Sacramento, California 95814

Commission Report 82-33
September 1982

CONTENTS

Page

PREFACE ix

ONE: ENGINEERING SUPPLY AND DEMAND 1

Shortage Theory 1
Surplus Theory 10
Conclusion 17

TWO: PROGRAMS AND ENROLLMENTS 21

Engineering and Computer Science Programs in California 21
California State University 25
  Engineering 25
  Engineering Technology 28
  Computer Science 28
University of California 30
  Engineering 30
  Computer Science 35
Independent Colleges and Universities 37
Issues in California Engineering and Computer Science Education 37
  Limits on Admission 40
  Student Preparation 42
  Articulation of Community College and University-Level Programs 43
  Placement of Graduates 43
  Cooperation with Secondary Schools and Industry 44
  Continuing Education 45
  Program Planning 45
Conclusion 46

THREE: FACULTY 47

The National Shortage of Engineering Faculty 47
California State University 50
  Resignations and Retirements 50
  Faculty Recruitment 51
University of California 53
  Resignations and Retirements 53
  Faculty Recruitment 54
Conclusion 55

FOUR: EQUIPMENT AND FACILITIES 57

California State University 59
University of California 61
Conclusion 62

FIVE: STUDENTS AND THEIR PREPARATION 65

The Decline in Student Numbers 65
The Decline in Student Preparation 65
Weaknesses of Science and Mathematics Teaching in Elementary and Secondary Schools 71
Weaknesses in California 75
Conclusion 77

SIX: INDUSTRY AND GOVERNMENT INCENTIVES FOR TECHNOLOGICAL EDUCATION 79

New Industrial Incentives 79
Federal Incentives 82
State Incentives 82
Conclusion 85

SEVEN: IMPLICATIONS FOR STATE AND INSTITUTIONAL POLICY MAKERS 87

Programs and Enrollments 89
Placement of New Programs 89
Encouraging Graduate Enrollment 90
Reviewing the Costs and Benefits of International Enrollments 91
Improving Teaching and Research Conditions 95
Updating Equipment and Facilities 97
Improving Student Preparation 98
Increasing Support 99

REFERENCES 101

FIGURES

Page

1. Productivity Increases in Seven Industrialized Countries, 1968-1978 ix

2. Sources of Integrated Circuits, 1979 xi

3. Comparison of Projected Supply of and Demand for Electrical and Computer Engineers in U.S. Electronics Industries, 1981-1985 5

4. Demand for High-Technology Professionals and Degrees in Engineering Granted, 1950-1980 18

5. Undergraduate Enrollments in Engineering, California State University, Fall 1975 Through Fall 1981 26

6. Baccalaureate Degrees Conferred in Engineering, California State University, 1975-76 Through 1981-82 26

7. Graduate Enrollments in Engineering, California State University, Fall 1975 Through Fall 1981 . . 27

8. Master's Degrees Conferred in Engineering, California State University, 1975-76 Through 1981-82 27

9. Fall Term Enrollments and Baccalaureate Degrees Conferred Annually in Engineering Technology, California State University, 1975-76 Through 1981-82 29

10. Fall Term Undergraduate Enrollments and Baccalaureate Degrees Conferred Annually in Computer Science, California State University, 1975-76 Through 1981-82 31

11. Fall Term Master's Enrollments and Degrees Conferred Annually in Computer Science, California State University, 1975-76 Through 1980-81 31

12. Undergraduate Enrollments in Engineering, University of California, Fall 1975 Through Fall 1981 32

8

13. Baccalaureate Degrees Conferred in Engineering, University of California, 1975-76 Through 1980-81 32

14. Master's Enrollments in Engineering, University of California, Fall 1975 Through Fall 1981 33

15. Master's Degrees Conferred in Engineering, University of California, 1975-76 Through 1980-81 . . 33

16. Doctoral Enrollments in Engineering, University of California, Fall 1975 Through Fall 1981 34

17. Doctorates Conferred in Engineering, University of California, 1975-76 Through 1980-81 34

18. Fall Term Undergraduate Enrollments and Baccalaureate Degrees Conferred Annually in Computer Science, University of California, 1975-76 Through 1981-82 35

19. Fall Term Master's Enrollments and Master's Degrees Conferred Annually in Computer Science, University of California, 1975-76 Through 1981-82 36

20. Fall Term Doctoral Enrollments and Doctoral Degrees Conferred Annually in Computer Science, University of California, 1975-76 Through 1981-82 36

21. Enrollments in All Degree Levels in Engineering for Selected Ethnic Minorities and Females, California State University and University of California, 1976 Through 1980 39

22. Enrollments in All Degree Levels in Computer Science for Selected Ethnic Minorities and Females, California State University and University of California, 1976 Through 1980 . . . 39

23. Average Age of Baccalaureate Degree Recipients at the University of California and the California State University, 1976-77 to 1979-80 66

24. Average Numbers of Secondary School Science and Mathematics Teachers Produced in Teacher Training Programs at U.S. Colleges and Universities 74

TABLES

Page

1. Projected Market for Scientists and Engineers in 1990 by Field and Level of Training (All Scenarios) 13

2. Employment, 1978 and 1990 (Projected), and Average Annual Openings, by Occupation, 1978-90 15

3. Engineering Employment in California, 1980-1985 . . . 16

4. Annual Starting Salaries for Engineering and Computer Science Graduates, September 1, 1981 - August 31, 1982 for Commitments Made Prior to March 5, 1982 19

5. Engineering Degrees Awarded by ABET-Accredited Independent California Colleges and Universities, 1981 37

6. Number and Percent of Engineering Degrees Awarded by California Institutions and Nationally, 1981 38

7. Instructional Equipment Replacement Budget, California State University, 1976-77 to 1981-82 60

8. Instructional Equipment Replacement Budget, University of California, 1976-77 to 1981-82 . . . 62

9. Projected Changes in Enrollment of Traditional College-Age and Older Students, 1979-1990 67

10. Supply of High School Teachers in Selected Subjects by Number of States Reporting Shortages and Surpluses in 1980 and 1981 72

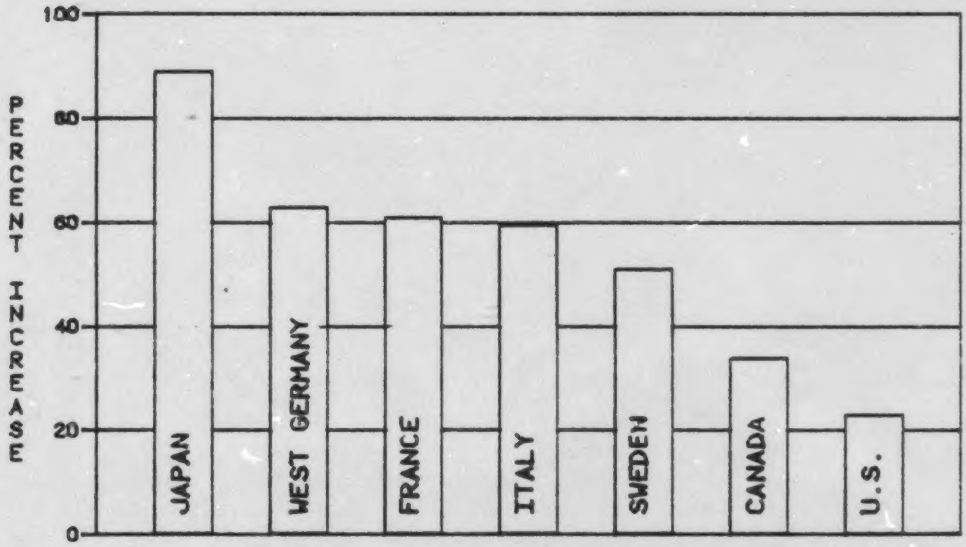
PREFACE

According to the World Bank, the United States ranked fourth among the nations in per-capita income in 1978, but dropped to fifth place in 1979, to sixth in 1980, to eighth in 1981, and so far in 1982 is tied for tenth place (Glower, 1982, p. 389). Without remedial action by industry and state and federal government, this decline will continue throughout the 1980s.

Remedial action will require increased technological research, development, and education to overcome America's lagging growth in productivity. As Figure 1 shows, its productivity grew less than 25 percent between 1968 and 1978, in contrast to that of Japan, West Germany, France, Italy, Sweden, and Canada. Research and development contribute up to half of America's per-capita income growth, and education adds almost a third (Hoy and Bernstein, 1981, p. 27); and if America is to retain its standard of living, let alone regain its competitive position among other nations, it must devote more attention to technological progress.

FIGURE 1

PRODUCTIVITY INCREASES IN SEVEN INDUSTRIALIZED COUNTRIES, 1968-1978



Source: Kahne, 1981, p. 51.

11

In 1980, new technology contributed more than $32 billion to America's gross national product, despite a total real dollar drop of some $192 billion in the GNP. And between 1948 and 1977, more than half of the nation's growth in productivity was attributable to technological advances, leading Frank Batton, president of the New York Stock Exchange, to state, "the most important source of productivity growth is the application of new technology to the production of goods and services" (1979).

Simon Ramo, co-founder and director of TRW Inc., states that "if broad technological inferiority should come to characterize America, living standards certainly would drop, our security would be threatened, and our economic competitiveness in world markets would collapse" (1981, p. 71E).

C. Lester Hogan, director of Fairchild Camera and Instrument Corporation, warns:

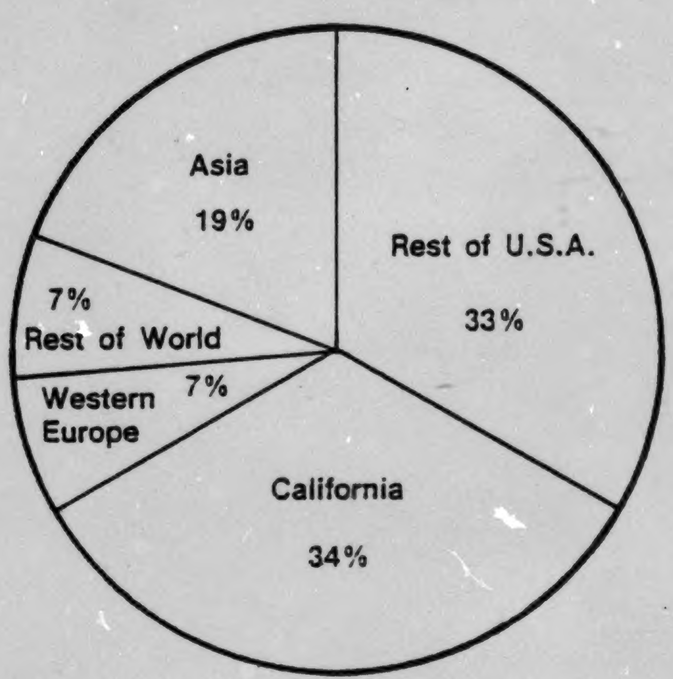
> As I look at the next ten years, I worry about international competition. If we lose the battle in the marketplace, we will lose because we do not have the quantity of trained people necessary to keep leadership in the industry. This is the single most important issue our industry faces--bar none! Other things will slow us down and make it tougher, but we can still win. The lack of qualified technical people, however, means we cannot win (American Electronics Association, 1981b, p. 1).

And Donald Glower of Ohio State University concludes, "the U.S. is engaged in an economic war for survival. We must commence immediately to bring our technical work force up to date with the state of the art. The continued improvement of our civilization includes strong dependence on the rate and quality of the development of new technology and its prompt attention to the production of goods and services" (1982, p. 389).

Clearly, the United States has an enormous task to do to regain its technological excellence. Among the states, California can help take the leadership in this effort. Its industries and government agencies employ approximately 21 percent of the nation's engineers and some 45 percent of the nation's computer specialists. Its economy involves a world-renowned technological base, as illustrated by the fact that its electronics firms supply a major share of the world's integrated circuits--fully a third in 1979, as Figure 2 shows. California is home for one-third of the nation's aerospace companies and provides one-fifth of America's aircraft manufacturing employment and three-fifths of its missile and space equipment manufacturing employment. It ranks as the fourth largest producer of gas and oil, and its mining is expected to be a growth industry

FIGURE 2

SOURCES OF INTEGRATED CIRCUITS, 1979



Source: Department of Electrical Engineering and Computer Sciences, University of California, cited in Investment in Economic Strength, 1981, p. 6.

in the next decade as the United States attempts to develop greater independence from foreign sources of critical minerals. The Governor's proposed "Investment in People" program represents a start toward this leadership effort, but an even greater commitment to technological education will be required if California is to maintain its technological advantages and contribute to state and national recovery.

With this conviction, the Commission staff has undertaken a study of the problems and prospects of engineering and computer science education in California in order to identify issues that will be confronting them in coming years as part of this effort. Assisting the staff has been a seven-member advisory committee, chaired by Russell L. Riese of the staff. Its members have included the following:

Representing the California State University:

Beaumont Davison, Dean
School of Engineering
California State Polytechnic University, Pomona

Anthony J. Moye, Assistant Vice Chancellor
Educational Programs and Resources
Office of the Chancellor

Representing the University of California:

James Albertson, Special Assistant
Systemwide Administration

John D. Kemper, Dean
College of Engineering
University of California, Davis

Representing the Association of Independent California Colleges and Universities:

Robert L. Heyborne, Dean
School of Engineering
University of the Pacific

Representing California Industry:

Kaye Kiddoo, Director of Personnel
Lockheed Corporation

To gather information from California's engineering and computer science programs, the Advisory Committee endorsed a ten-part questionnaire survey, covering (1) emerging engineering and computer science technologies, (2) enrollments and impaction, (3) admissions requirements and student preparation, (4) facilities, (5) equipment, (6) cooperative programs, (7) continuing education, (8) placement of graduates, (9) faculty characteristics, and (10) significant problems and issues of quality. The questionnaire was discussed with members of the Advisory Committee and other engineering school deans at meetings of the University of California's Council of Engineering Deans, the CSU Council of Engineering Deans, a group of deans from independent institutions, and of the Mathematics and Engineering Liaison Committees of the Articulation Council. The staff of the Commission is grateful for the thorough and thoughtful responses to the questionnaire provided by the deans and directors of all the engineering programs of the University of California and the California State University as well as the University of the Pacific and Loyola Marymount University. (Responses were not received from the California Institute of Technology, Harvey Mudd College, Northrop University, Stanford University, the University of Santa Clara, or the University of Southern California.)

During November and December, 1981, Russell Riese of the staff participated in and monitored the work of the Department of Economic and Business Development which led to the Governor's "Investment in People" program, while the staff of the Commission's Analytical Studies Division assembled data on enrollments, degrees conferred, and student ethnicity, sex, and age for California programs in these fields. These data were shared with the Department of Economic and Business Development for their use in the "Investment in People" program.

The Commission staff wishes to thank the Councils of Engineering Deans of the University of California and the California State University, the deans of several independent universities, and the Engineering and Mathematics Liaison Committees of the Articulation Council as well as the members of the Advisory Committee for their counsel and assistance during the course of the study.

This report is divided into seven chapters. The first describes the differing opinions about shortages or surpluses of supply of engineers, computer scientists, and other technologically skilled workers in American society, in order to provide background on the tasks confronting schools of engineering and computer science. The second identifies the engineering and computer science programs in California's colleges and universities, reports their enrollments, and discusses their major problems regarding enrollments. The third describes the shortage of engineering and computer science faculty nationally and in California, with particular emphasis on the California State University and the University of California. The fourth identifies pressing problems of equipment and facilities --including not merely deferred maintenance and replacements but also the lack of technologically advanced equipment already used in industry. The fifth points to sources of inadequate preparation of students, both nationally and in California. The sixth notes incentives that industry are providing universities and that states are providing to their public universities to develop technological expertise. And the seventh summarizes the report by pointing to the educational and financial implications of issues discussed in the previous chapters for educational policy makers in California.

CHAPTER ONE

ENGINEERING SUPPLY AND DEMAND

Productivity and the economic health of the United States are increasingly dependent on the fruits of engineering. A major concern exists that the supply of engineers and mathematicians and certain other science professionals may not keep pace with the demand. If it does not, the chances for economic growth are in jeopardy. Because there are differences of opinion relative to supply and demand for engineering, mathematics, and computer science graduates, a brief review of current literature on the subject is warranted. The opinions expressed in the literature can be divided into two main groups: those who believe there are shortages, and those who perceive there are surpluses.

SHORTAGE THEORY

Typical of the shortage theorists is the October 1980 federal report on Science and Engineering Education for the 1980s and Beyond, prepared jointly by the National Science Foundation and the Department of Education, which highlighted the nation's concern with the professional education of scientists, engineers, and technicians. It expressed these concerns as follows:

> The economic well being, security, and health and safety of Americans during the remaining two decades of this century, and beyond, will depend increasingly on our ability as a Nation to strengthen our technological and scientific enterprise. Several other countries are challenging our leadership in science and technology. During the coming decades, we are likely to be confronted with increasing competition, both from already industrialized countries and from those newly emerging industrialized countries with enormous labor resources. The United States cannot compete successfully in this environment unless it strengthens its technological base. This, in turn, will require that the Nation have sufficient numbers of engineers, scientists, and technicians with the skills and training required to meet present and future challenges, and that we make effective use of those skilled personnel (p. 8).

The report arrived at ten principal findings, each of which was discussed in detail. Briefly they are:

1. There are, at present, shortages of trained computer professionals and most types of engineers at all degree levels. In contrast, the current supply of scientists is adequate to satisfy existing demand for their service, except in a few subfields of physical and biological science.

2. Projections indicate that in 1990 the aggregate number of new science graduates at all degree levels should exceed the number able to find jobs in the broad fields in which they are trained. With the possible exception of a few subfields, the numbers of new engineering baccalaureates should, by 1990, be adequate to satisfy projected demand for their services. However, the adequacy of Ph.D. engineers in 1990 is problematic. The current shortage of trained computer professionals at all degree levels is expected to persist beyond 1990.

3. While considerable progress has been made in increasing the representation of minorities, women, and the physically handicapped, all three groups continue to be underrepresented in the science and engineering professions. The number of women in engineering schools has been increasing rapidly, and they now compose about 15 percent of freshman enrollments. With this exception, the proportion of minorities and women who major in science and engineering is still small relative to their proportion among college students.

4. There is an immediate problem of providing for the acquisition, retention, and maintenance of high-quality faculty to teach engineering and computer courses. This problem is the result of several factors, including rapidly increasing undergraduate enrollments, decreasing Ph.D. output, a widening gap between academic and nonacademic salaries, and the obsolescence of facilities and technical resources needed for research.

5. The high cost of maintaining existing laboratory apparatus and of replacing obsolete apparatus and facilities is a severe problem for university faculty who engage in research in equipment-intensive fields such as electrical engineering, computer science,

physics, chemistry, and the life sciences. In some cases instruments needed to carry out research at the frontiers of these fields are available only at centralized facilities, and this situation is affecting the education of advanced graduate students.

6. Although industrial design and engineering practices have changed rapidly under the impact of modern electronic technology, engineering schools, in general, lack sufficient resources to modernize teaching facilities and equipment, with the result that many new engineers and computer professionals are not adequately trained in state-of-the-art techniques.

7. Decreasing priority is being given to science and mathematics in secondary schools. This situation is in marked contrast to Germany, Japan, and the Soviet Union, which have been pursuing a policy of more extensive and rigorous education in science and mathematics for all citizens. While the qualifications of U.S. secondary school graduates who intend to pursue college majors in science and engineering remain high, the general quality of science and mathematics instruction at the secondary level has deteriorated since the 1960s, as has the scientific and mathematical competence of students who are not motivated toward careers in science and engineering.

8. At both the secondary and higher education levels, there is a serious problem of reduced educational standards and requirements. Inadequate attention is paid to motivating and providing an appropriate education in science and technology for those who do not intend to pursue science and engineering as careers but who need an understanding of them for their work and in their lives. A shortage of mathematics and science teachers and the absence of adequate teacher support resources at the secondary level hampers the ability of the schools to provide science and mathematics instruction for those not likely to follow science and engineering careers.

9. There is a noticeable absence of coordination among the various components of the science and engineering education system, particularly between the secondary and the college and university levels. This lack of coordination is evidenced, for example, by: (a) reduced opportunities for sustained interactions

between university and secondary school science and mathematics faculties; (b) the insufficient attention paid to the special problems of two-year community colleges which are assuming an increasing share of the responsibility for training the Nation's skilled technical work force; and (c) the dispersion of the responsibility for continuing education among many types of providers and the isolation of continuing education from the formal educational system.

10. Media which focus attention on science and technology, including newspapers, magazines, public radio and television, science and technology museums, and related institutions enjoy considerable popularity among nonscientists and nonengineers. However, these media have not been systematically exploited as adjuncts to the formal education system (pp. 16-17).

A second example of shortage theory is represented by the American Electronics Association's 1981 Blue Ribbon Committee on Engineering Education. The charge of the Association's Board of Directors to this select group of industrial executives and educational leaders was to study the problem of engineering shortages, certify its existence and degree, identify the major barriers, and recommend a plan for Association action. The AEA Committee found that:

- An increasing national shortage of engineers threatens to limit the growth of high technology and negatively impact the economic and political leadership of the United States, as well as the continued health and expansion of the electronics industries (1981a, p. 1).

- The growing shortage of engineers on a national scale threatens to limit the growth of high technology and negatively impacts the continued health and vitality of the United States on economical, political, and social levels (p. 6).

- Currently, the shortage in B.S. graduates is caused by a lack of resources--most seriously in faculty--of universities to educate the oversupply of qualified high school graduates (p. 10).

- The shortage in M.S. and Ph.D.s is caused by an undersupply of graduate students resulting primarily from high B.S.-level industrial salaries and disincentives to enter teaching careers, not only limiting industry's progress in advanced research, but clearly reducing the pool from which faculty come (p. 10).

- The present situation in engineering undergraduate education is characterized by plenty of students, but too few resources to educate them without risking a loss in quality (p. 16).

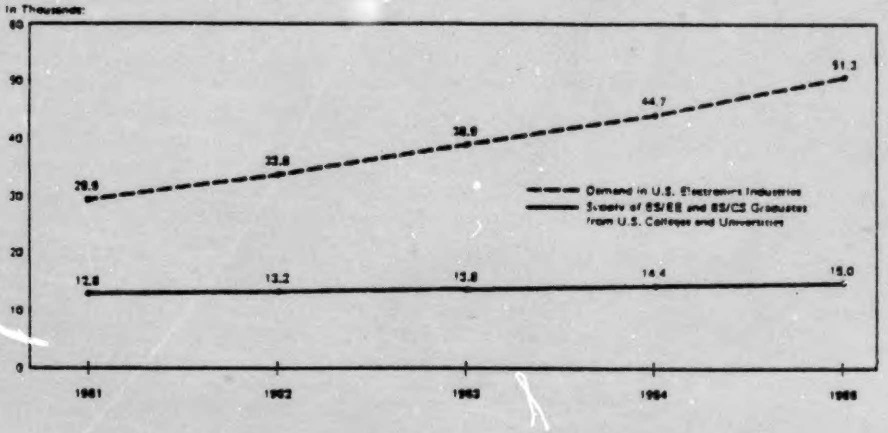
The Committee's comparison of projected supply and demand for electrical and computer engineers is shown in Figure 3. The supply shortfall by 1985 projects to about 129,000, or 25,000 annually. Just to meet the needs of the electronics industry, the Committee estimated that educational institutions must triple their output of electrical and computer engineers each year for the next five years.

The Committee concluded:

> The United States is still the most productive country in the world. Yet while others improve their ratio of output-per-worker, America does not--dropping from a WW II 2.9% increase to a minus 0.9% in 1979.
>
> Japan's productivity makes U.S. industries jog faster to run the economic mile. On a per capita basis, Japan has fewer than 1/20th the lawyers, 1/7th the accountants, but 5 times as many engineers as the United States.

FIGURE 3

COMPARISON OF PROJECTED SUPPLY OF AND DEMAND FOR
ELECTRICAL AND COMPUTER ENGINEERS IN U.S. ELECTRONICS INDUSTRIES
1981-1985



Source: American Electronics Association, 1981a, p. 7.

The Soviet Union's double time to reach "scientific and technological supremacy"--graduating 6 times as many undergraduate engineers as the U.S.--causes discomfort in America's national defense arenas.

According to a 1977 NSF study, high technology has twice the productivity, triple the real growth, six times fewer price increases, and nine times more employment when compared to low technology industries. Electronics in particular holds the promise of winning on the economic, political, and social fronts--if the engineer shortages are reversed.

> The lack of electronic and computer science engineers may be the single most important factor limiting the growth and continued vitality of electronics industries.
>
> Dr. William Perry, Partner, Hambrecht & Quist, Former U.S. Undersecretary of Defense for Research and Engineering (p. 22).

In order to alleviate the engineering shortage, AEA has set an industry-wide standard for giving resources to education at 2 percent of a company's R&D expenditures. Such resources can be given directly by a company to a college or through the AEA created foundation. Suggested uses for these resources include: equipment, adjunct or visiting professors, teaching "chairs", graduate fellowships, and general grants.

A third shortage theorist is Stephen Kahne, Director of the National Science Foundation's Division of Electrical, Computer, and Systems Engineering, who stated in 1981:

> It is no longer an open question whether the shortage of electrical engineers in the United States is or is not a crisis. It is. Sooner or later every U.S. industry dependent upon electrical engineering will be affected--and there are more such industries now than ever. Toy and automobile manufacturers, even textile and clothing companies, have discovered the value of electronics and computer-based systems in their products or manufacturing processes. Indeed, these new industries, previously unaffected by electrical engineering in any significant way, are the hidden factor that invalidates traditional market surveys of future needs for EEs. It is hard to predict the growing need for electronics specialists in sectors of the economy that never before employed them (IEEE Spectrum, June 1981, p. 50).

Similarly, representatives of government, academia, industry, and the technical community testified before the House Committee on Science and Technology on October 6 and 7, 1981, that national security and the U.S. economy are threatened by looming shortages of engineers and technically educated people (The Institute, January 1982, p. 6).

Other shortage theorists abound. For example, George A. Keyworth, science advisor to President Reagan, has committed his office to facilitating efforts to cope with the current crisis in engineering education. These efforts will have three major thrusts: (1) development of a manifesto signed by key U.S. leaders stating engineering education's problems and possible solutions, (2) creation of model programs for sharing limited engineering and science talent between academia and industry, and (3) consideration of a scheme to allow industries to contribute to a university equipment-leasing fund (The Institute, January 1982, pp. 1, 6).

Joseph M. Pettit, President of the Georgia Institute of Technology, has called engineering supply and demand in the United States "a current crisis." He states,

> In the United States at this time we are undergoing what must be called a crisis in engineering education, and indeed in the supply of engineers for industry and government . . . . The fact is we have a serious imbalance among (1) a high industrial demand for engineers, (2) a low graduation rate, especially at the master's and doctoral level, (3) a high undergraduate enrollment, (4) a shortage of engineering professors, and (5) old and obsolete laboratory equipment, financial constraints, etc. (1981, p. 26).

Courtland Perkins, President of the National Academy of Engineering, in an editorial entitled, "The Growing National Crisis in Engineering Education," declared that "the defense of the country and its economic growth are both endangered by the decline in available engineering talent resulting from serious problems existing in our engineering education programs" (1981, p. 1). He pointed out that the crisis comes from the fact that many students are not being properly educated, due principally to a shortage of competent faculty and adequate teaching facilities.

Arthur Hansen, President of Purdue University, states that the term "crisis" appropriately describes the current problem of providing scientific and technological manpower. He describes several proposals on how the United States can recover its position as a technological leader and how to remain competitive economically. Among these proposals are increased pay for skilled military personnel, increased in-service training for teachers in mathematical and scientific education in our primary and secondary schools, motivation of students by government, industry and education to pursue courses in science and mathematics, and encouraging education, government, industry and professional societies to address the problem of growing faculty shortages (1981, pp. 20-24).

Dr. Evan Metcalf, Director of the Economic Development Program of the Western Interstate Commission for Higher Education, has concluded that engineers are in critically short supply in all engineering disciplines, despite some variation in specific specialties. He foresees this high demand lasting at least through 1990, with annual job openings nationwide expected to increase from 69,000 in 1980 to 75,000 in 1985 and to 82,000 in 1990. Contrasted with these numbers, the number of graduates are expected to increase from 58,000 in 1980 to 73,000 in 1985 and to only 65,000 in 1990. In the western states, his data indicate annual average job openings for 5,400 engineers in the Mountain states and 20,000 if the Pacific states are added. This compares to 4,000 graduates currently in the Mountain states and an additional 6,000 in the Pacific states. Added to these demands from the nation's industrial economy must be the impact of expanded defense spending which total approximately 46,400 additional engineers (Western Interstate Commission for Higher Education, 1981, p. 11).

The New England Board of Higher Education has expressed its concern as to whether New England will successfully retain its human capital and corporate resources because of fierce competition from the sunbelt. In Massachusetts alone, which accounts for nearly half of New England's gross product, it estimates an annual shortfall of 3,000 engineers and computer scientists. The Board concludes,

> Vigorous growth in high technology industries is now hindered by demand outstripping the supply of professional and technical specialists required for computer and electronic design and production. New England must not only attract from other states qualified newcomers who recognize the healthy state of the regional economy, but its institutions of higher education must provide the electronics engineers and computer scientists who are perpetually in such short supply (Hoy and Bernstein, 1981, p. 18).

The Board expects the shortage of engineers and computer scientists to shrink somewhat because the supply of engineers is projected to rise by almost 50 percent between 1975 and 1985, but the shortage will still be felt well into the mid-1980s as employments needs continue to expand (p. 42).

A year ago, the New York Times asked leaders from industry in various parts of the nation what they considered to be critical issues affecting the world of work. High on their lists, besides the state of the economy, productivity, and energy, was the pressing shortage of engineers and technically trained workers. For example, Walter Fallon, Chairman of Eastman Kodak, citing the burgeoning demand for technological expertise, anticipated an increasing need for mechanical, chemical, electrical and industrial engineers along with expertise in computer science and added that the percentage of the population seeking these careers falls far short of the demand. Lewis Branscomb, vice president and chief scientist for International Business Machines, expanded on the theme of the growing need for technological expertise. William Andrews, chairman and president of Scovill Inc., cited a need for engineers and physicists, skilled machinists, and other technical workers. Recruiting specialists reported their difficulty in hiring engineering graduates. The College Placement Council noted that engineering students comprised about 7 percent of 1980 graduates but received about 65 percent of the job offers. And computer-science experts called the shortage of qualified people "a national crisis." The Times noted that California accounts for a quarter of the nation's job increases, although it represents only 10 to 11 percent of the nation's total wage and salary employment. Because California has traditionally received over a fourth of the Defense Department's budget, the impact of increased defense spending on the State should be positive (New York Times, 1981).

The latest article on the shortage of engineers appeared in the January 6, 1982, Chronicle of Higher Education. It described two surveys which indicated that 1982 graduates in "engineering and computer science will have the best chances of getting job offers." One of the surveys, conducted by the Northwestern University Placement Office, concludes that 1982 job opportunities for engineers will increase by 11 percent over last year. The second, conducted by Michigan State University's Placement Office, concludes that the overall demand will be about the same as last year and that there will be more demand in engineering and computer sciences than there are graduates to meet the demand. The Northwestern report estimates salary offers will increase by 9.2 percent, while the Michigan State study estimates an increase of 5.2 percent. Highest starting salaries will be paid to chemical, electrical, and mechanical engineers--more than $22,000 per year. Computer sciences majors, will earn $19,763. In contrast, social science majors, who are at the bottom of the scale will earn an average of only $14,112 ("Two Surveys Find Job Opportunities Good for Engineers," 1982, p. 10).

SURPLUS THEORY

In contrast to these pessimistic forecasts, other observers foresee surpluses of engineers--or at least no crises. For example, the reality of the crisis was debated at an October 1981 Engineering Manpower Conference sponsored by the Institute of Electrical and Electronic Engineers. Those attending--managers, engineers, personnel directors, and academics--were asked, "is there really a shortage of engineers?" Although they agreed that a few specific engineering specialties are experiencing shortages, no consensus was reached as to whether or not there is an overall manpower shortage. Some participants sensed a general shortage caused by U.S. Government actions in the past, but if the Government had a rational plan to educate and use engineers there would be no manpower problem; others believed that there is only a shortage of entry-level engineers, that engineers of 10 or more years of experience are not being fully utilized, and that full utilization would eliminate any manpower shortages; and others expressed the view that the major shortage is in engineering faculty. But even here, David Lewis, scientific projects officer in the Office of Naval Research, stated that the only faculty problem is obtaining faculty at the salaries that universities are willing to pay, and another participant concluded that there was no faculty shortage but, rather, too many schools (The Institute, January 1982, p. 7).

Bruno Weinschel, chairman of the Engineering Affairs Council of the American Association of Engineering Societies (AAES), which represents 43 engineering societies with individual memberships exceeding one million engineers and computer scientists, expressed the following skepticism about the problem:

- On claims of shortage: "I believe there are openings in academia, but the data on the overall engineering shortage are much more difficult to establish."

- On a report of the American Electronics Association that claimed current shortages and far worse ahead: "It's my feeling that the defense industry is outbidding the civilian industries. We know that certain defense contractors try to make a good impression on the Government by exaggerating the number of engineers employed, possibly by misclassifying lesser-qualified people as engineers. And, if several contractors expect to win the same contract, they may make their projections of future manpower needs accordingly, so AEA figures from large employers could be badly distorted by the number of engineering openings claimed by large defense contractors."

- On the future of U.S. industry: "The companies the AEA surveyed are claiming major growth through the decade, but will all the AEA members grow at their forecasted rate or will many fail? Everywhere you look, there are erosions of the U.S. engineering and high-technology industries--the automotive, aerospace, and even semiconductor industries are some examples. The Japanese are aiming straight at Intel and they say so specifically."

- On utilization of engineers: "You have to agree that it's cheaper to hire a new engineer and bring him somewhere. Also, not all our employers are enlightened to the benefits of human capital--of engineers who have benefited from continuing education, for example" (ibid.).

A summary of the Engineering Manpower Conference states:

> IEEE leaders are worried that current forecasts of engineering shortages from industry, Government, and academia could fuel an engineering manpower glut and result in massive layoffs reminiscent of those that occurred in the U.S. in the early 1970s. They point for corroboration of their worst fears to the recessionary climate now being experienced in the semiconductor, automotive, and electrical manufacturing industries, where factories have been closed and layoffs have been taking place (ibid., p. 1).

A Roundtable of the National Academy of Engineering, convened to discuss and to chart a course for education and utilization of engineers through the year 2000, has reviewed the first phase of a major study of this topic conducted by the Assembly of Engineering at the request of the National Science Foundation and has concluded:

1. There is no comprehensive understanding of the system that trains and utilizes engineers.
2. There is a dearth of hard, believable data to back up anecdotal evidence of manpower shortages, to distinguish exactly where the problems are, or to confidently forecast trends (National Academy of Engineering, Roundtable, 1981, p. 6).

The Roundtable report states:

> There was no consensus that engineering, as a whole, is in a crisis situation. Some acknowledged there may be

> isolated crises, or spot problems in manpower demands for some industrial disciplines or for college teaching faculty, but felt there was a lack of credible data to confirm or quantify these perceptions. They questioned, also, whether such problems might not be self-correcting, or whether "solutions" to these problems, applied without sufficient knowledge of the system behavior, might ultimately swamp the demand for engineers with an oversupply (p. 6).

The report of the National Science Foundation and the Department of Education, *Science and Engineering Education for the 1980s and Beyond*, quoted at the beginning of this chapter, stated that "there are, *at present*, shortages of trained computer professionals and most types of engineers at all degree levels" (underlining added). But frequently its words "at present" are overlooked by many readers. By 1990, approximately 360,000 scientists and over one million computer professionals and engineers will be needed to fill growth and replacement demands (p. 28). Yet projections from the National Center for Education Statistics (NCES), which were used in the NSF/DOE report as the supply component, indicate that about 3.4 million science and engineering baccalaureates and 630,000 science and engineering master's degrees will be awarded between 1978 and 1990. Thus projected baccalaureates in all engineering fields, including those in engineering technology, may exceed demand by almost 1.8 times the projected baseline openings. Only two fields, computer sciences and statistics, may have large deficits of people, although under certain conditions, shortages may also occur in industrial, nuclear, and aeronautical engineering. The NSF/DOE projected market for scientists and engineers in 1990 are shown in Table 1. This table does not point toward a "crisis" status for engineers and scientists. In fact, the NSF/DOE report states, "In general, the numbers of new science graduates should widely exceed the number who will be able to find jobs in the disciplines in which they are trained . . . . These projections indicate that for engineers with bachelor's or master's degrees, the labor market in 1990 should be less tight than at any time since the early 1970s as a result of faster expansion in the supply of qualified personnel than in demand for their services" (p. 26).

Irwin Feerst, a consulting engineer, a former engineering professor at Adelphi University, and the leader of the 3,000 member Committee of Concerned Electrical Engineers, a group that considers as a sham the American Electronics Association report predicting a shortfall of 25,000 engineers annually through 1985, insists that "the whole thing is a scam to get gullible young people to fill college classrooms, there never has been a shortage of engineers." He charges that the AEA figures are "inaccurate, biased, ambiguous and based on duplication of data" because they are based on a poorly worded

TABLE 1

PROJECTED MARKET FOR SCIENTISTS AND ENGINEERS IN 1990 BY FIELD AND LEVEL OF TRAINING (ALL SCENARIOS)

	Baccalaureates and Masters	*Doctorates*
Physical Sciences	Adequate	Adequate
Atmospheric	Balance	
Chemical	Adequate	
Geological	Adequate	
Physics and Astronomy	Adequate	
Engineering	Adequate	Uncertain
Aeronautical	Balance-Shortage[1]	(Possible shortages some fields)
Chemical	Adequate	
Civil	Adequate	
Electrical	Adequate	
Industrial	Shortage	
Mechanical	Adequate	
Metallurgical	Adequate	
Mining	Adequate	
Petroleum	Balance	
Other	Adequate	
Mathematical Sciences	Adequate	Adequate
Mathematicians	Adequate	
Statisticians	Shortage	
Computer Professions	Shortage	Shortage
Life Sciences	Adequate	Adequate
Agricultural	Adequate	Adequate
Biological	Adequate	Adequate
Social Sciences	Adequate	Adequate
Psychologists	Adequate	
Other	Adequate	
All Fields	Adequate	Adequate

[1] Shortage under expanded defense spending assumption only.

NOTE: "Adequate" indicates that projected supply exceeds projected demand. "Balance" indicates that projected supply is close to projected demand. "Shortage" indicates that projected supply is less than projected demand. "Uncertain" is used for doctoral engineers because NSF projects an adequate supply in 1990 whereas BLS projects a shortage in 1985.

Source: National Science Foundation and U.S. Department of Education, 1980, p. 26.

survey to which 671 member companies responded. He also claims that, under the laws of supply and demand, entry-level salaries should rise to $30,000 and experienced engineers should be earning double their current salaries if an engineering shortage existed ("Keeping Track on 'The Engineering Shortage,'" 1981).

Jon Sargent, a labor economist for the U.S. Bureau of Labor Statistics (BLS), has stated, "The BLS estimates that, by 1990, the number of college graduates will have exceeded the available technical and professional jobs by more than three million, resulting in higher unemployment, lower starting salaries, and a large spillover into jobs graduates once shunned" (New York Times, 1981, p. 29).

Harrison Shull, provost at Rensselear Polytechnic Institute and chairman of the National Academy of Sciences' Commission on Human Resources, who has been following freshman enrollments in engineering, claims that the swing to oversupply in engineering could come in two to three years. The 1980 entering engineering class was 110,000. If they finish at the same rate as their predecessors over the past 10 years, 75,000 engineering graduates would be entering the job market. Mr. Shull has stated, "Glut is too big a word for it, but there would be a modest surplus in supply" (New York Times, 1981, p. 10).

The Bureau of Labor Statistics expects good employment opportunities for engineers through the 1980s, but it does not anticipate a manpower "crisis". According to projections from the National Center for Education Statistics, about 81,400 bachelor's degrees in engineering will be awarded annually during the decade of the '80s. In the 1960s, 85 percent of the bachelor's degree recipients in engineering, including those who went to graduate study, actually entered the field. This proportion dropped to 80 percent during the mid-1970s. If the 80 percent rate continues, an average of 65,000 are expected to enter the field annually. Some engineering positions will continue to be filled by graduates from mathematics, physics, and other related disciplines. According to the BLS, the projected large increase in engineering degrees may result in more limited opportunities than in the past for transfers from related fields. The numerical data for engineering supplied by the BLS is as follows (Bureau of Labor Statistics, 1980):

Employment, 1978	1,136,000
Projected employment, 1990	1,441,000
Percent growth, 1978-90	26.8
Average annual openings, 1978-90	46,500
Growth	25,500
Replacement	21,000

Degrees in engineering (including engineering technology)	Actual 1977-78	Projected 1978-79 (annual average)
Bachelor's degrees	56,009	81,441
Master's degrees	16,409	16,772
Doctoral degrees	2,440	3,158

These data indicate that the annual average supply will exceed demand once the current shortage is satisfied. A breakdown by specific options is presented in Table 2.

Based on these data, one would not anticipate that current spot shortages will persist. Indeed, Neal Rosenthal, chief of occupational outlook at the BLS, believes "the supply should start to balance out the demand (from industry) as we get further into the 1980s" (The Wall Street Journal, August 20, 1981).

Finally, one must turn to data from California's Employment Development Department (EDD). Portions of two tables contained in the Department's Projections of Employment, 1980-85, are reproduced in

TABLE 2

EMPLOYMENT, 1978 AND 1990 (PROJECTED), AND AVERAGE ANNUAL OPENINGS, BY OCCUPATION, 1978-90

					Annual Average Openings, 1978-90		
Occupation	HEGIS Code	Estimated Employment, 1978	Projected Employment, 1990	Percent Change, 1978-90	Total	Employment Change	Replacement Needs
Engineers	0900	1.136,000	1,441,000	26.8	46,500	25,500	21,000
Aerospace	0902	60,000	70,000	20.7	1,900	1,000	900
Agricultural	0903	14,000	17,800	26.8	600	300	300
Biomedical	0905	4,000	5,100	26.8	175	100	75
Ceramic	0916	14,000	17,800	26.8	550	300	250
Chemical	0906	53,000	63,000	20.0	1,800	900	900
Civil	0908	155,000	190,000	22.8	7,800	2,900	4.900
Electrical	0909	300,000	364,000	21.5	10,500	5,400	5,100
Industrial	0913	185,000	233,000	26.0	8,000	4,000	4,000
Mechanical	0910	195,000	232,000	19.1	7,500	3,100	4,400
Metallurgical	0914	16,500	21,300	29.0	750	400	350
Mining	0918	6,000	9,500	58.3	600	300	300
Petroleum	0907	17,000	23,400	37.6	900	550	350

Source: Bureau of Labor Statistics, 1980.

Table 3. The table shows total engineering employment in California in 1980 and projected employment in 1985. It also shows projected demand over the same period of time, with a 4.29 job opportunity ratio (annual average increase in need) for all of engineering. During the 1975-1980 period, engineering degree output from the University, State University, and independent institutions has been on a steady increase of approximately 10 percent per year. However, at the M.S. and Ph.D. levels, output has declined an annual average of 1.8 percent and 1.6 percent, respectively. While California institutions have been able to increase their output of B.S. degrees to nearly double the rate of need as indicated by the EDD if current immigration rates hold for engineers, they appear to have fallen woefully short in maintaining a balance in graduate degrees. California is not unique. All other states have had substantial increases in undergraduate enrollments and baccalaureate degrees, while graduate enrollments have dropped substantially because of the attractive salaries paid by industry to those persons completing a bachelor's degree program. This is why many authors have been concerned about our continuing to "eat our seed corn." If colleges and universities are not able to supply people with advanced degrees for both industry and education (the teaching faculty of tomorrow--the topic of Chapter Three), we will no longer be able to provide quality educational opportunities. We will have indeed eaten the seed corn.

TABLE 3

ENGINEERING EMPLOYMENT IN CALIFORNIA, 1980-1985

Occupational Category	Total All Industries		Net Demand From Industry Change	Job Opportunities, 1980 to 1985			
	1980	1985		Replacement Needs Due to Labor Force Separations	Total Job Opportunities From These Sources	Average Annual Job Opportunities	Job Opportunity Ratio
Engineers, Technical	268555	300497	31943	25611	57554	11511	4.29
Engineers, Aero-Astronautic	21786	22368	582	1772	2354	471	2.16
Engineers, Chemical	5875	6692	818	591	1409	282	4.80
Engineers, Civil	31121	34344	3224	3674	6898	1380	4.43
Engineers, Electrical	73989	83485	9496	5059	14555	2911	3.93
Engineers, Industrial	41883	47820	5937	4395	10332	2066	4.93
Engineers, Mechanical	32995	35214	2219	3615	5834	1167	3.54
Engineers, Metallurgical	2226	2508	282	229	511	102	4.59
Engineers, Mining	474	602	128	115	243	49	10.25
Engineers, Petroleum	1832	1863	31	193	224	45	2.45
Engineers, Sales	7379	8117	738	897	1635	327	4.43
Engineers, Other	48997	57484	8488	5071	13559	2712	5.53
Computer Specialists	74637	87037	12401	4181	16582	3316	4.44
Computer Programmers	44351	51253	6903	2390	9293	1859	4.19
Computer Systems Analysts	25482	30203	4721	1524	6245	1249	4.90
Other Computer Specialists	4805	5581	777	267	1044	209	4.35

Source: Employment Development Department, 1979, pp. 48, 58.

CONCLUSION

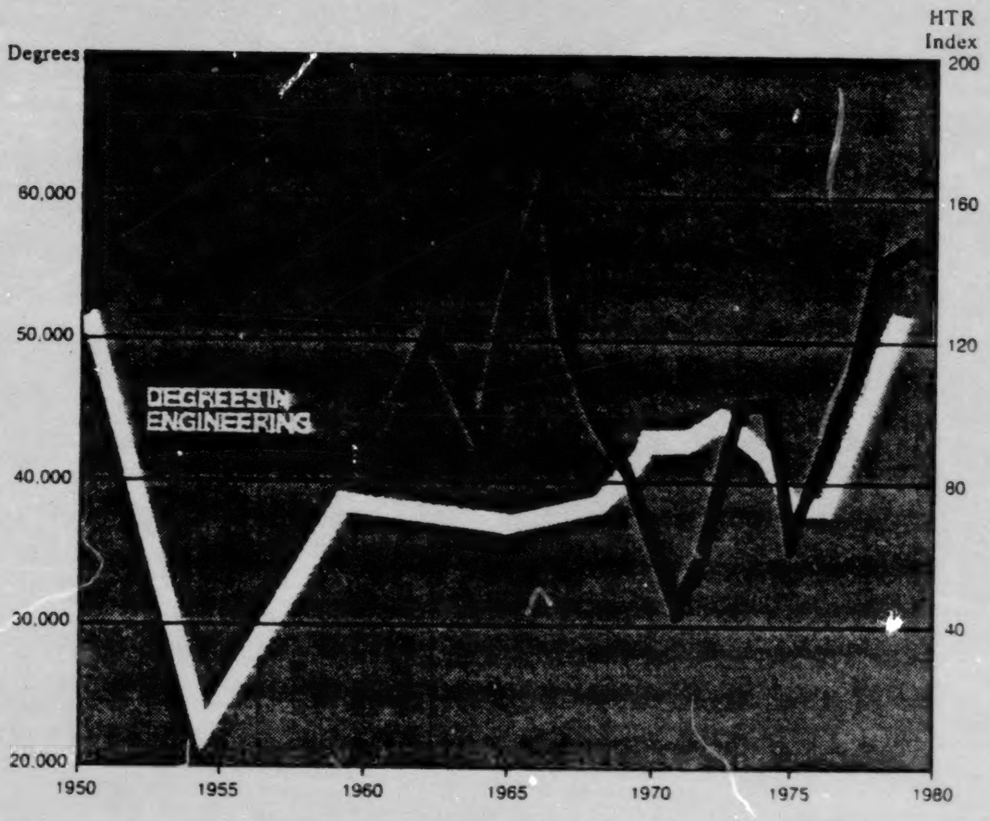
When one reads that search firms are being paid up to $10,000 to locate a $30,000 engineer, that Loral Electronics pays $5,000 for referral of an engineer with four years of experience, that three Lockheed divisions pay employees $1,000 for each engineer they refer, that the engineering graduate has an average of 10 job offers from which to choose, that students are signing agreements in their junior year that include employment guarantees and sometimes even the relocation of girlfriends or boyfriends, that the number of certifications from the Department of Labor for permanent hiring of aliens which are very costly to the employer has quadrupled in four years, that Rockwell with 17,000 engineers on the payroll looked to hire 900 more in 1981, that the California Society of Professional Engineers reports that Hughes Aircraft is short 2,000 technical employees and that Hewlett Packard has a shortfall of 2,500 employees, and that Vandenberg Air Force Base has announced a 14-month delay in launching the first military payloads aboard the space shuttle because of a shortage of engineers, one must conclude that a current shortage of engineers clearly exists in certain specialties.

Yet current shortages do not necessarily imply future scarcity. Science, mathematics, and engineering manpower forecasts do not have a good track record, since employment demand fluctuates so greatly. For instance, since 1961, Deutsch, Shea & Evans Inc., has maintained a "High Technology Recruitment Index" measuring the demand for engineers and technical professionals based on advertising. Figure 4 shows the changes in this recruitment index along with the fluctuations in numbers of engineering degrees at the baccalaureate level over the past 30 years (Deutsch, Shea & Evans, Inc., 1979). As can be seen, college and university production of engineering graduates in the United States have often been out of synchronization with the demand for engineers. Enrollments expand in response to rising demand but, due to the time factor involved, often overshoot the mark, and students then find themselves in a downward swing in the economy. By the time enrollments respond to the swing downward, the demand is once again on the rise and is in excess of the supply. One can easily associate the two curves in Figure 2 with history. In the mid-1960s, the recruitment index was high but enrollments did not respond by increasing until the early 1970s. By that time, demand had dropped due to large cuts in NASA and defense spending. The supply of engineers greatly exceeded the demand in the early 1970s. The current expansion in engineering enrollments raises the spectre that another cycle of shortage and surplus may be in the offing.

So far, however, the job market remains tight for engineers in all fields and at all degree levels. Even the recent downturn in the economy has not appreciably influenced the demand for engineering or computer science graduates. Although the High Technology Recruitment Index of Deutsch, Shea & Evans dropped from 147 in January 1981 to 126 by December before rising to 131 for January 1982 (1961 = 100), and although Deutsch, Shea & Evans see no reasonable grounds to believe that the downturn has leveled out or is in the process of turning around ("Decline in Technical Demand Index Expected to Continue," 1982, p. 22), so far this reduced demand has simply amounted to graduates having fewer offers from which to select.

FIGURE 4

DEMAND FOR HIGH-TECHNOLOGY PROFESSIONALS
AND DEGREES IN ENGINEERING GRANTED, 1950-1980



Source: Deutsch, Shea & Evans, Inc., 1979.

Demand continues to exceed supply, and salaries for technical graduates continue to increase. Table 4 reports the average salary offers made through March 5, 1982, to engineering and computer science students graduating between September 1, 1981, and August 31, 1982, according to data from 184 placement offices at 161 colleges and universities participating in the annual starting salary survey of the College Placement Council. As of that date, 20,608 offers had been made to bachelor's degree candidates, 1,842 to inexperienced master's degree candidates, and 207 to doctoral candidates. Engineering disciplines accounted for 60 percent of all bachelor's degree offers, and computer science majors received the most offers of all. In terms of starting salaries, petroleum engineering leads the field, with an average monthly offer of $2,536--an increase of 15 percent since July 1, 1981. Chemical engineering is second, at $2,264 per month--up 11.5 percent over July. And other engineering specialties increased from 5 to 14 percent.

Certainly program planners in higher education should not assume that demand for engineering and computer science graduates will always outstrip supply, and obviously college and university pro-

TABLE 4

ANNUAL STARTING SALARIES FOR ENGINEERING AND COMPUTER SCIENCE GRADUATES, SEPTEMBER 1, 1981 - AUGUST 31, 1982 FOR COMMITMENTS MADE PRIOR TO MARCH 5, 1982

Specialty	B.S.	Inexperienced M.S.	Ph.D. Average	Percentiles 90th	50th	10th
Aeronautical	$22,896					
Chemical	26,952	$29,712	$35,376	$38,400	$35,700	$31,200
Civil	23,496	27,036	31,908			
Electrical (Comp. Engr.)	24,504	28,032	35,988	39,600	36,252	30,996
Geological	26,952					
Industrial	24,312	27,336				
Mechanical	25,248	27,900				
Metallurgical	25,440					
Mining	25,308					
Nuclear	24,012	27,744				
Petroleum	30,432					
Engr. Average	25,476					
Computer Science	22,008	25,560				

Source: The College Placement Council, March 1982 grams should not be expanded exponentially to meet potentially temporary shortages. But particularly in California, educational planners can expect continued high demand for these graduates through the mid-1980s.

CHAPTER TWO

PROGRAMS AND ENROLLMENTS

The attraction of job opportunities at high salaries for beginning engineers has lured more and more students to choose engineering and computer science as their majors since the mid-1970s. The number of baccalaureate degrees awarded in these fields nationally in 1981--69,170--was up 88 percent from 1976 and 100 percent from 1973, and this number could reach 80,000 by 1984. Already, 74 out of every 1,000 bachelor's degrees conferred are awarded in engineering, compared to only 40 in 1977.

Engineering enrollments have been expanding similarly in California's colleges and universities, although limits are now having to be placed on admissions to programs in public universities because of faculty and resource shortages. This chapter describes trends in California enrollments as well as several specific issues and problems involving these programs that warrant the attention of State and institutional policy makers.

ENGINEERING AND COMPUTER SCIENCE PROGRAMS IN CALIFORNIA

Twenty-six colleges and universities in California offer engineering programs accredited by the Accreditation Board for Engineering and Technology (ABET), formerly the Engineers' Council for Professional Development--the agency recognized by the U.S. Secretary of Education and the Council on Postsecondary Accreditation as the national accrediting authority concerning the quality of engineering and engineering technology programs offered by educational institutions in the United States. Of those 26, 25 have been surveyed by the California Postsecondary Education Commission regarding their engineering programs. (Data were not requested from the U.S. Naval Postgraduate School because most of its graduates are not available upon graduation for general recruitment by industries in California.) The Commission also surveyed the University of California at San Diego, even though at the time of the survey none of its engineering programs were accredited by ABET. (Since then, its electrical engineering program has been accredited.)

The engineering programs accredited by ABET at each campus surveyed by the Commission include the following (Accreditation Board for Engineering and Technology, 1980):

CALIFORNIA STATE UNIVERSITY

California Polytechnic State University, San Luis Obispo

- Aeronautical
- Agricultural
- Architectural
- Civil
- Electrical
- Electronic
- Environmental
- Industrial
- Mechanical
- Metallurgical

California State Polytechnic University, Pomona

- Aerospace
- Chemical
- Civil
- Electrical and Electronic
- Industrial
- Mechanical

California State University, Chico

- Civil
- Electrical and Electronic
- Mechanical

California State University, Fresno

- Civil
- Electrical
- Mechanical
- Surveying and Photogrammetry

California State University, Fullerton

- Engineering

California State University, Long Beach

- Chemical
- Civil
- Computer Science and Engineering
- Electrical
- Engineering
- Materials
- Mechanical
- Ocean

California State University, Los Angeles

- Civil
- Electrical
- Mechanical

California State University, Northridge

- Engineering

California State University, Sacramento

- Civil
- Electrical and Electronic
- Mechanical

Humboldt State University

- Environmental Resources Engineering

San Diego State University

- Aerospace
- Civil
- Electrical
- Mechanical

San Francisco State University

- Engineering

San Jose State University

- Chemical
- Civil
- Electrical
- Industrial and Systems
- Materials
- Mechanical

UNIVERSITY OF CALIFORNIA

University of California, Berkeley

- Chemical
- Civil
- Electrical Engineering and Computer Sciences
- Industrial Engineering and Operations Research
- Materials Science and Engineering
- Naval Architecture
- Nuclear Engineering and Electrical Engineering and Computer Sciences
- Nuclear Engineering and Mechanical Engineering
- Sanitary
- Transportation

University of California, Davis

- Agricultural
- Chemical
- Civil
- Electrical
- Mechanical

University of California, Los Angeles

- Engineering

University of California, Irvine

- Civil
- Electrical
- Mechanical

University of California, Santa Barbara

- Chemical
- Electrical
- Mechanical
- Nuclear

ACCREDITED INDEPENDENT COLLEGES AND UNIVERSITIES

California Institute of Technology

Aeronautics
Chemical
Engineering and Applied Science
Environmental Engineering Science

Harvey Mudd College

Engineering

Loyola Marymount University

Civil
Electrical
Mechanical

Northrop University

Aerospace
Electronic
Mechanical

University of the Pacific

Civil
Electrical

University of Santa Clara

Civil
Electrical Engineering and Computer Science
Mechanical

University of Southern California

Aerospace
Chemical
Civil
Civil Engineering/Building Sciences
Electrical
Industrial and Systems
Mechanical
Petroleum

Stanford University

Aeronautical and Astronautical
Chemical
Civil
Electrical
Industrial
Mechanical
Petroleum

(This list of accredited programs illustrates a difference in institutional philosophy on accreditation. Some institutions seek ABET accreditation for each special major in engineering while others seek accreditation for only generic engineering although they offer many options, specializations, or concentrations under this general accreditation.)

Beyond these campuses, the Commission has sought information on computer science programs from all 19 State University campuses, all eight general campuses of the University, and all eight independent colleges and universities having accredited engineering programs. The following sections of this chapter report enrollment and degree trends in engineering and then computer science first for the California State University, then the University of California, and finally the independent institutions before turning to general admission and enrollment problems facing all segments of California higher education in these two fields.

CALIFORNIA STATE UNIVERSITY

Engineering

Twelve of the 13 State University campuses surveyed offer majors in civil, electrical and mechanical engineering. (The exceptior is Humboldt which offers a baccalaureate program in environment/resource engineering only.) Four campuses offer majors in chemical engineering--Northridge, Long Beach, Pomona, and San Jose. Other engineering majors, including agricultural, aeronautical, industrial, petroleum, and environmental engineering are offered on only one, two, or at most three campuses. At most campuses, computer engineering (electrical design of computers) is an integral part of the electrical or electrical/electronic engineering program.

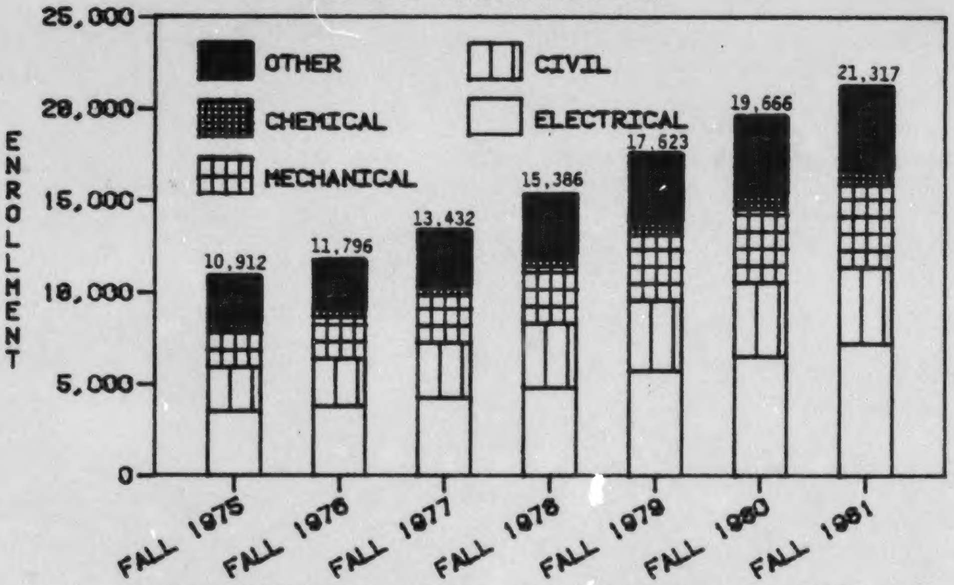
Figure 5 displays the growth since 1975 in total undergraduate engineering enrollments in the 13 State University campuses surveyed. These enrollments have nearly doubled since 1975, reaching 21,317 students in fall 1981. All majors, including electrical, mechanical, civil, chemical, and other engineering, have had nearly proportional increases. (Undergraduate enrollment data from California State University, Northridge, were not provided by majors, and its engineering enrollment has been separated into these five areas by applying ratios from systemwide data.)

Figure 6 shows that the number of baccalaureate engineering degrees conferred during the same period has increased by 120 percent. Baccalaureate degrees in electrical engineering have increased by 133 percent, civil by 94 percent, mechanical by 160 percent, chemical by 206 percent, and others by 83 percent.

Nine of the State University campuses offer graduate programs in engineering. The three largest programs are at San Jose, Long Beach, and Pomona. These three campuses account for approximately 53 percent of the master's degrees awarded in engineering in the system. Figures 7 and 8 indicate that graduate trends in the State

FIGURE 5

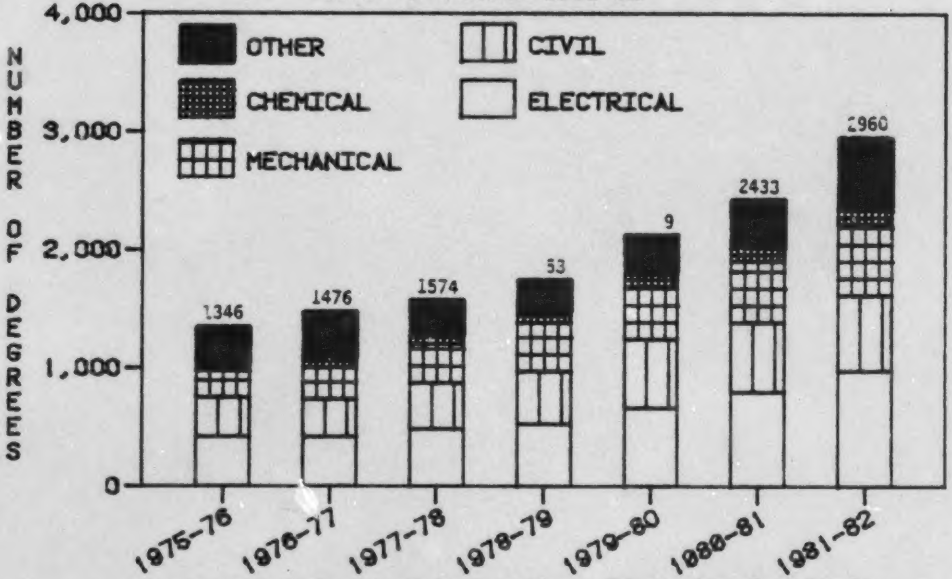
UNDERGRADUATE ENROLLMENTS IN ENGINEERING
CALIFORNIA STATE UNIVERSITY
FALL 1975 THROUGH FALL 1981



Source: California Postsecondary Education Commission

FIGURE 6

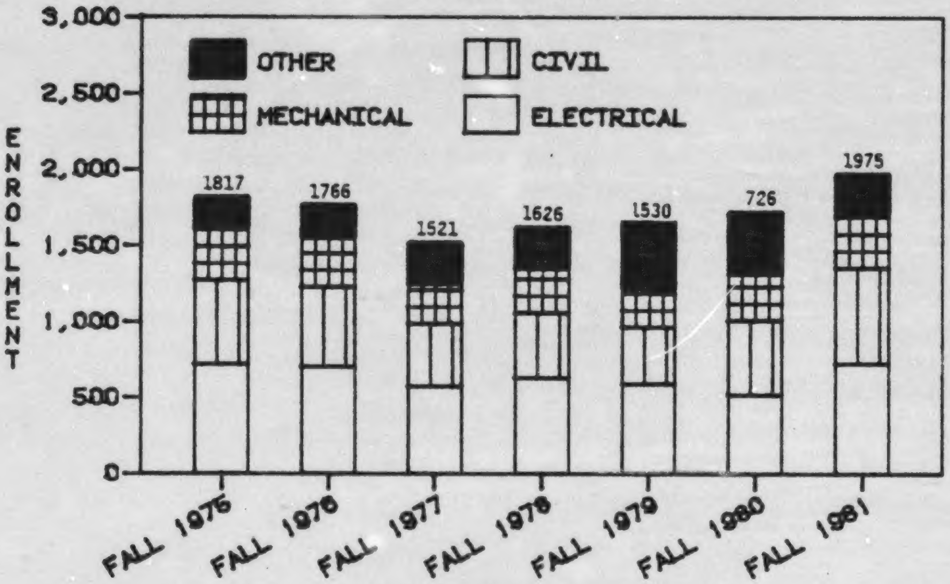
BACCALAUREATE DEGREES CONFERRED IN ENGINEERING
CALIFORNIA STATE UNIVERSITY
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

FIGURE 7

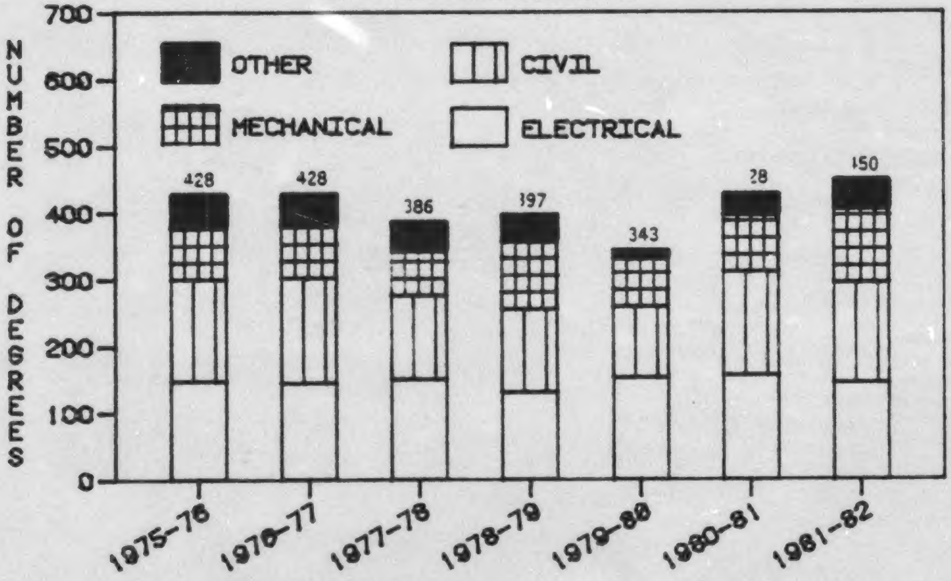
GRADUATE ENROLLMENTS IN ENGINEERING
CALIFORNIA STATE UNIVERSITY
FALL 1975 THROUGH FALL 1981



Source: California Postsecondary Education Commission

FIGURE 8

MASTER'S DEGREES CONFERRED IN ENGINEERING
CALIFORNIA STATE UNIVERSITY
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

University reflect what is happening nationally at the graduate level--until 1981 both enrollments and master's degrees conferred remained below the 1975 level.

Engineering Technology

The Accreditation Board for Engineering and Technology defines engineering technology as that part of the technical field which requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer. The engineering technology curriculum has less depth in mathematics, sciences, and engineering sciences than the engineering program but provides more training in skills. Experience has shown that many technologists have careers in engineering after several years of experience and further in-house company training.

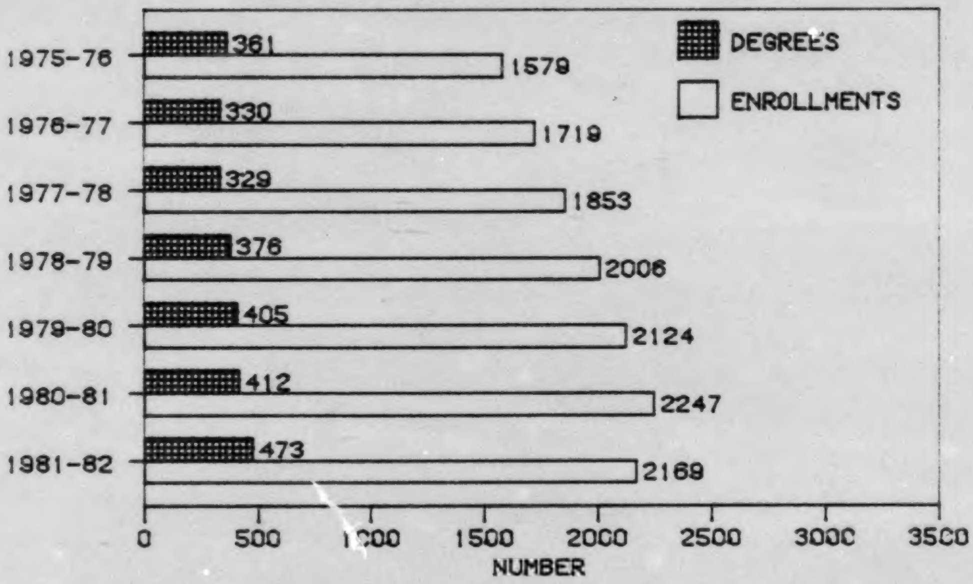
Since technology programs bear an important relationship to engineering, it is important to consider enrollments and degrees granted in this field. Four of the 13 State University campuses surveyed also offer bachelor's degree programs in engineering technology--San Luis Obispo, Pomona, Sacramento, and San Jose. San Luis Obispo offers five majors--air conditioning and refrigeration, mechanical, electrical, manufacturing processes, and welding. Pomona offers electronics, aerospace, construction manufacturing, and mechanical technology. Sacramento limits its programs to mechanical and construction technology and San Jose offers aeronautics only. Figure 9 shows the growth in these programs since 1975. Enrollments in 1981-82 have increased by 36 percent over those in 1975-76 while degrees conferred have increased by 31 percent. Approximately one-third of these enrollments and degrees granted are in aeronautics, one-fourth in mechanical, one-fifth in electrical, and the remainder in other technologies.

Computer Science

Educational programs directed toward computers are generally divided into two categories--(1) computer hardware design, which is usually associated with an electrical or electronic engineering program or at a few institutions is given the separate title of computer engineering; and (2) computer applications, which is frequently tied to a mathematics program. Many computer applications courses are taught in business, psychology, educational testing, and other areas. Occasional computer courses in these subject fields as an aid in data processing are not classified as

FIGURE 9

FALL TERM ENROLLMENTS AND BACCALAUREATE
DEGREES CONFERRED ANNUALLY IN ENGINEERING TECHNOLOGY
CALIFORNIA STATE UNIVERSITY
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

computer science, but concentrated studies in computer applications generally are classified as computer science provided they are based on curricula as outlined by the Association for Computing Machinery.

Nine State University campuses have offered such computer science curricula at the baccalaureate level since 1975. Three more added computer science in 1978 as did two in 1979 and one in the winter term of 1982. At the master's level, five campuses offered such programs in 1975, with one added each in 1977, 1980, and 1981.

Computer science is the fastest growing subject area in the State University. Undergraduate enrollments have increased by over 500 percent since 1975 and master's enrollments by 375 percent. The degree output is small but nevertheless it increased by over 250 percent at both the B.S. and the M.S. level between 1975 and 1981. Figure 10 shows bachelor's degrees awarded and Figure 11 shows enrollments since 1975 in these programs stressing computer applications, and master's degrees and enrollments for the same period. The high ratio of enrollments to degrees conferred appears to stem from four reasons: (1) the programs are relatively new (several have not been in existence long enough to produce graduates); (2) they enroll a high percentage of part-time students; (3) many of their students satisfy their objectives without completing the full degree program; and (4) their dropout rates may be high.

UNIVERSITY OF CALIFORNIA

Engineering

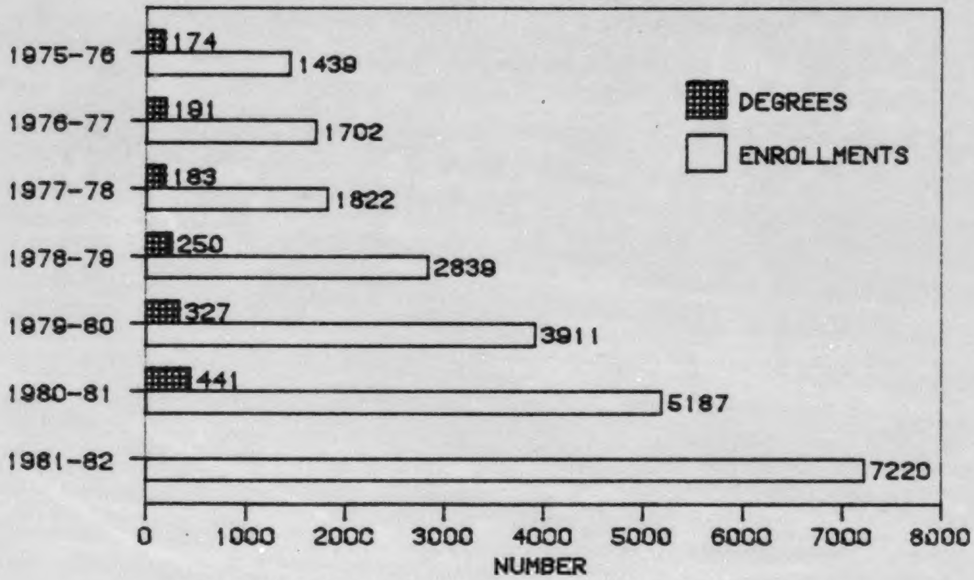
Figures 12 and 13 provide a graphic display of the growth in baccalaureate engineering enrollments and degrees conferred by the University of California over the past six years. Enrollments increased by 154 percent and the number of B.S. degrees awarded increased by 84 percent, with the growth of degrees in individual majors varying considerably--computer engineering increased by 244 percent, electrical engineering (which includes computer engineering on some campuses) increased by 138 percent, chemical engineering by 179 percent, mechanical engineering by 128 percent, and civil engineering by 40 percent. The only category that showed a decrease (38 percent) is the "other" classification, which includes aerospace, systems, nuclear, and other relatively low-enrollment majors. (Undergraduate enrollment data from UCLA was not provided by majors, and its total engineering enrollment has been separated into these six categories by applying ratios from systemwide data.)

Graduate enrollments and degrees awarded at both the master's and doctoral level (illustrated in Figures 14 through 17) have followed what has been observed as a national trend, that is, decreases in the late 1970s followed by a small upward trend in the early 1980s. While undergraduate enrollments increased by 154 percent over the past six years, enrollments at the master's level have essentially been static (Figure 14) and the number of master's degrees conferred in 1980-81 was fewer than in the mid-1970s (Figure 15). Doctoral enrollments dipped in 1977 but by 1980-81 were slightly above the 1975 level (Figure 16). The number of doctorates declin-

(Text continues on page 35.)

FIGURE 10

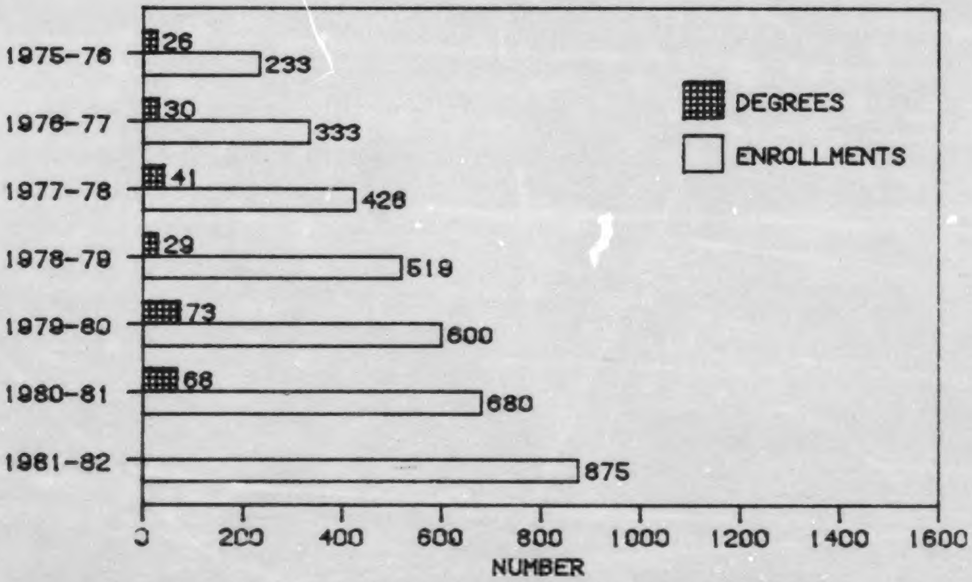
FALL TERM UNDERGRADUATE ENROLLMENTS AND BACCALAUREATE
DEGREES CONFERRED ANNUALLY IN COMPUTER SCIENCE
CALIFORNIA STATE UNIVERSITY
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

FIGURE 11

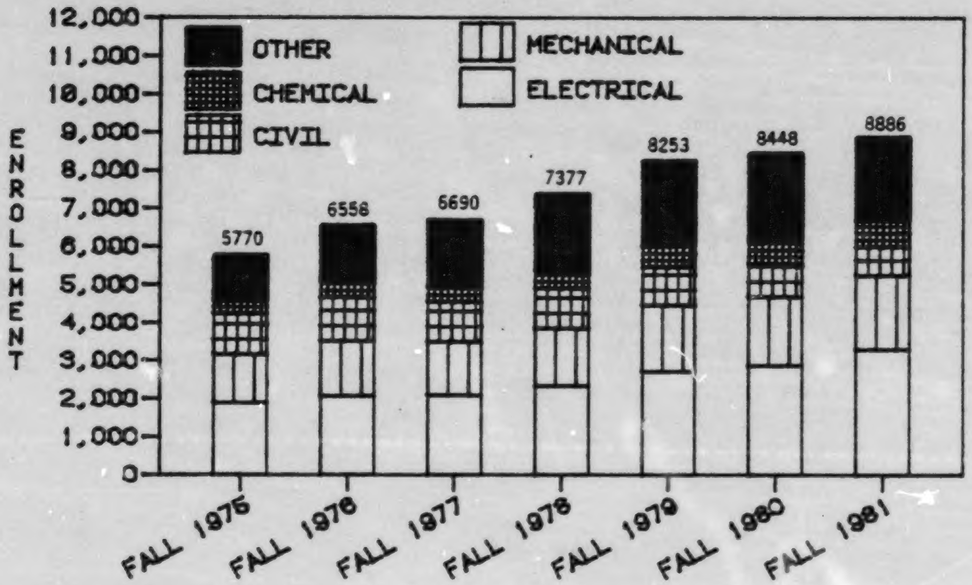
FALL TERM MASTER'S ENROLLMENTS AND DEGREES
CONFERRED ANNUALLY IN COMPUTER SCIENCE
CALIFORNIA STATE UNIVERSITY
1975-76 THROUGH 1980-81



Source: California Postsecondary Education Commission

FIGURE 12

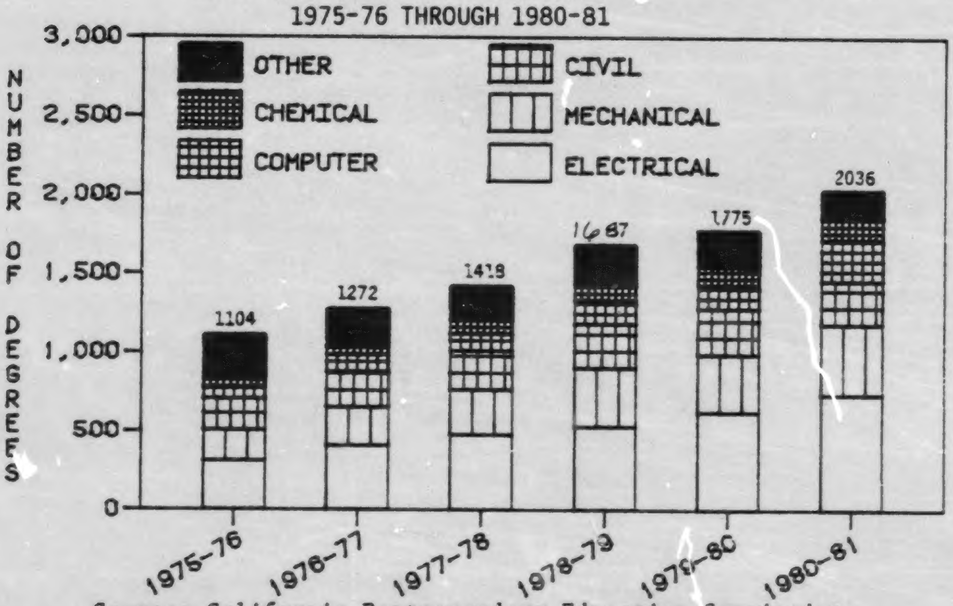
UNDERGRADUATE ENROLLMENTS IN ENGINEERING
UNIVERSITY OF CALIFORNIA
FALL 1975 THROUGH FALL 1981



Source: California Postsecondary Education Commission

FIGURE 13

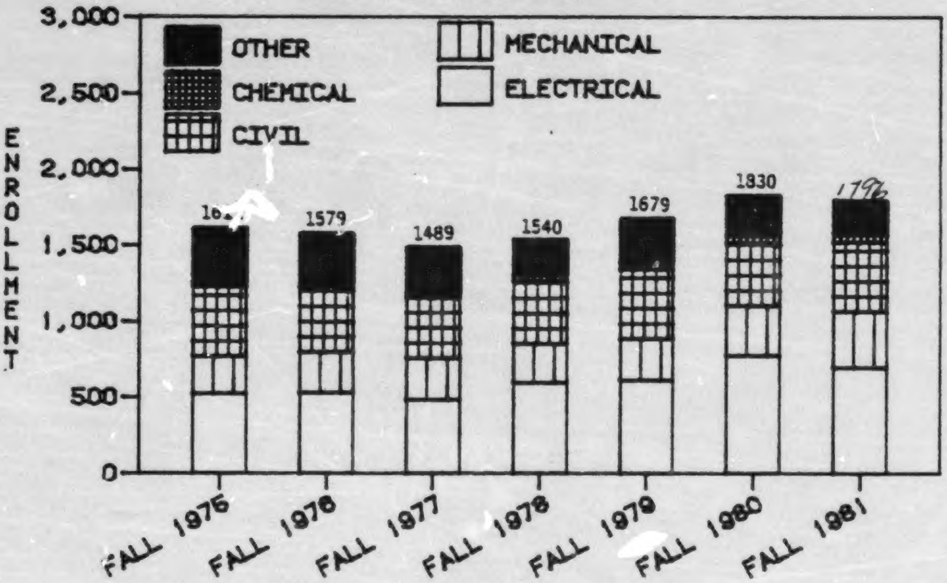
BACCALAUREATE DEGREES CONFERRED IN ENGINEERING
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1980-81



Source: California Postsecondary Education Commission

FIGURE 14

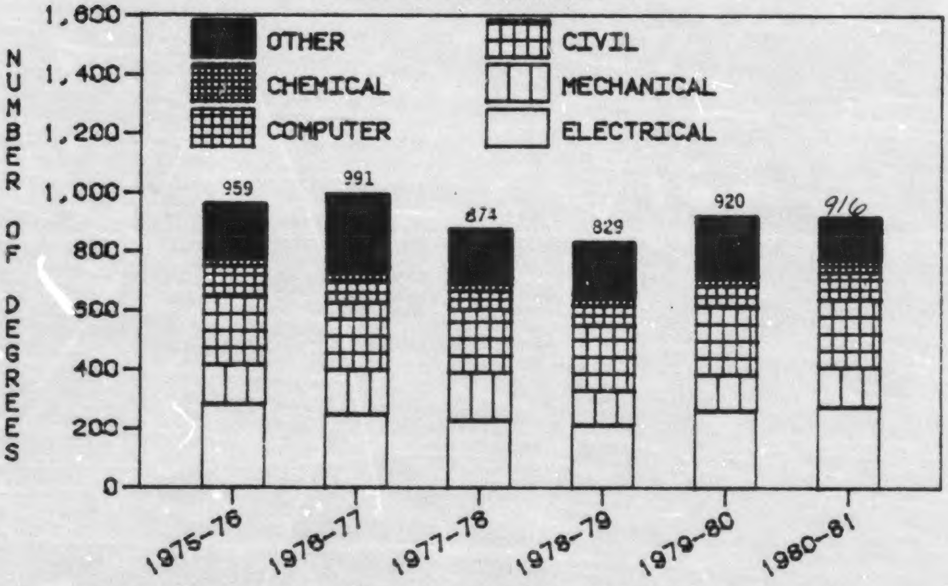
MASTER'S ENROLLMENTS IN ENGINEERING
UNIVERSITY OF CALIFORNIA
FALL 1975 THROUGH FALL 1981



Source: California Postsecondary Education Commission

FIGURE 15

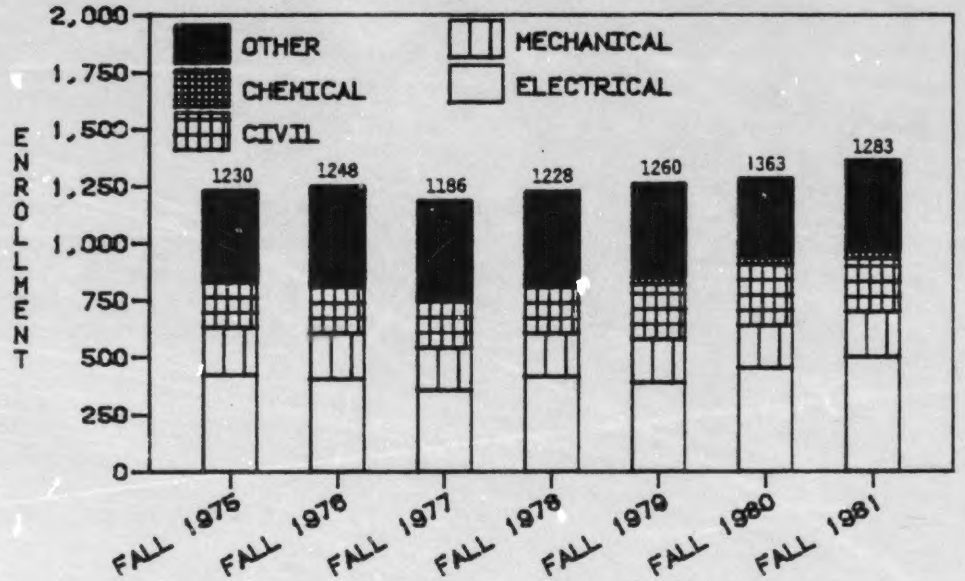
MASTER'S DEGREES CONFERRED IN ENGINEERING
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1980-81



Source: California Postsecondary Education Commission

FIGURE 16

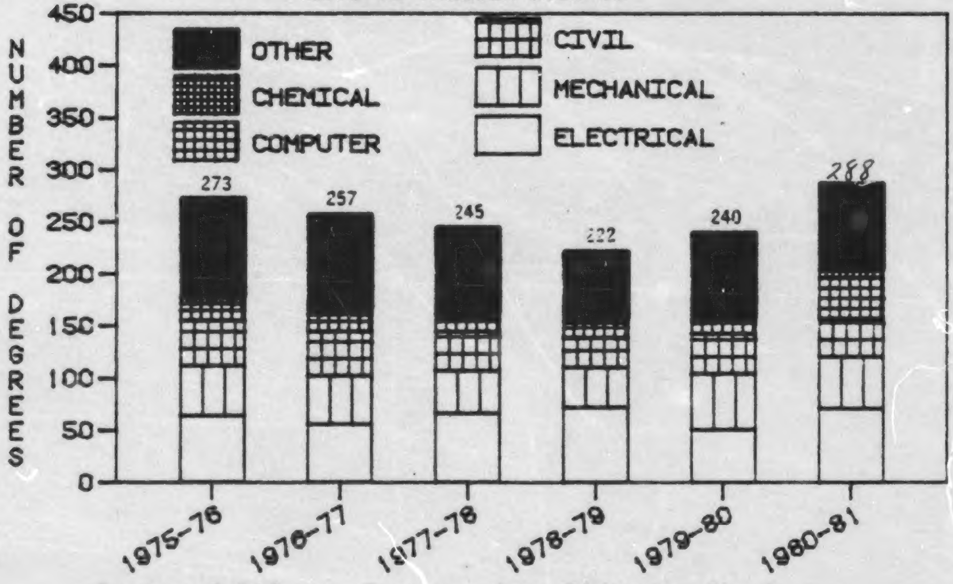
DOCTORAL ENROLLMENTS IN ENGINEERING
UNIVERSITY OF CALIFORNIA
FALL 1975 THROUGH FALL 1981



Source: California Postsecondary Education Commission

FIGURE 17

DOCTORATES CONFERRED IN ENGINEERING
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1980-81



Source: California Postsecondary Education Commission

ed by 20 percent between 1975-76 and 1978-79, then rose to 5 percent above the mid-1970 level in 1980-81 (Figure 17). Clearly, the number of graduate degrees conferred no longer bears a relationship to the increase in undergraduate degrees. Since graduates with a bachelor's degree can obtain reasonably well-salaried positions in industry, they have little incentive at this time to pursue advanced degrees. Chapter Seven discusses several incentives the State could employ to encourage more engineering students to enter graduate education and discusses the lack of graduate enrollments in detail.

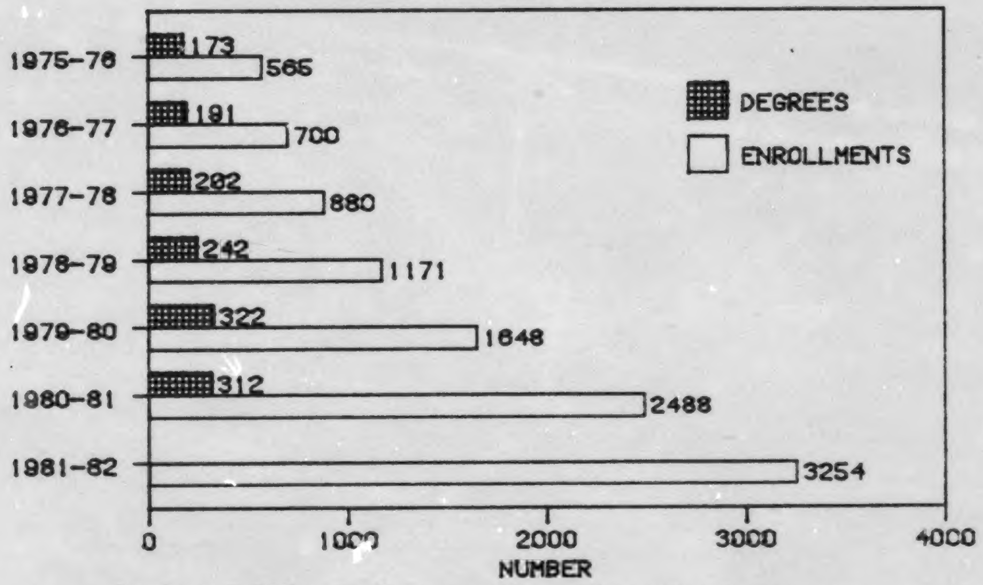
Computer Science

Figure 18 displays the changes taking place in undergraduate computer science enrollments and in computer science degrees granted by the University of California. Enrollments are increasing at an exponential rate but the number of degrees granted is increasing slowly, indicating that students are apparently obtaining their objective without completing the full baccalaureate program or are dropping out before completing their degrees.

Figure 19 shows that at the master's level, enrollments and the number of degrees granted decreased substantially from 1975-76 to 1979-80 but are now showing an increase. Doctoral degrees and enrollments have followed the same pattern as seen in Figure 20, with enrollments in 1981-82 slightly above 1975-76 levels.

FIGURE 18

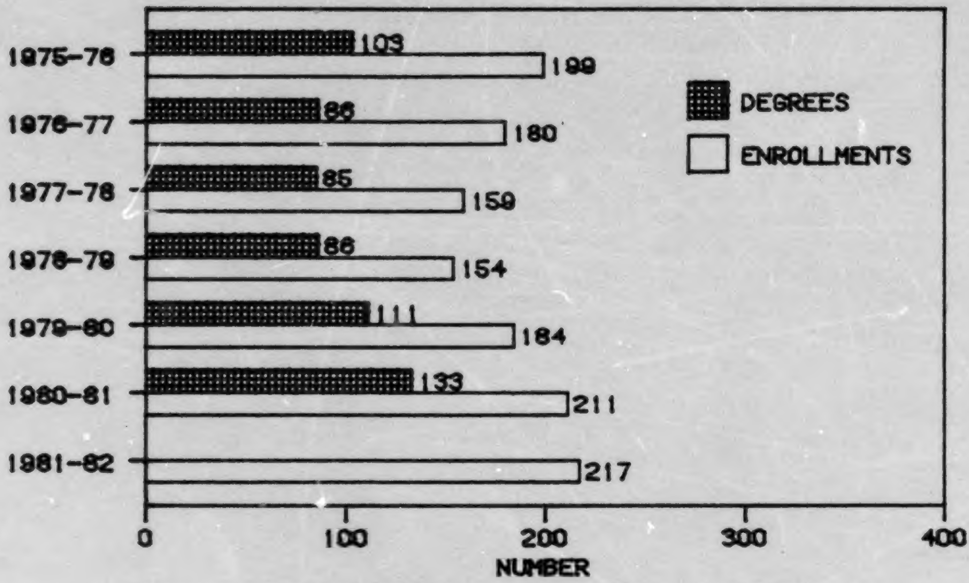
FALL TERM UNDERGRADUATE ENROLLMENTS AND BACCALAUREATE
DEGREES CONFERRED ANNUALLY IN COMPUTER SCIENCE
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

FIGURE 19

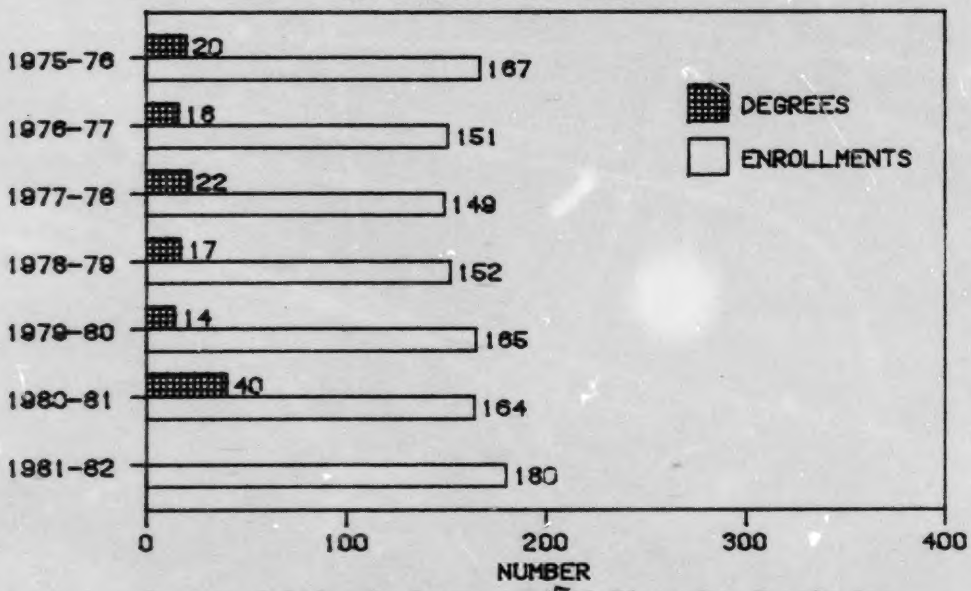
FALL TERM MASTER'S ENROLLMENTS AND MASTER'S DEGREES
CONFERRED ANNUALLY IN COMPUTER SCIENCE
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

FIGURE 20

FALL TERM DOCTORAL ENROLLMENTS AND DOCTORAL DEGREES
CONFERRED ANNUALLY IN COMPUTER SCIENCE
UNIVERSITY OF CALIFORNIA
1975-76 THROUGH 1981-82



Source: California Postsecondary Education Commission

INDEPENDENT COLLEGES AND UNIVERSITIES

The number of engineering degrees granted by each of the accredited independent institutions in 1981 appears in Table 5, based on data compiled by the Engineering Manpower Commission. The Commission's Information Digest indicates the total B.S. degree output in engineering of all independent institutions would be approximately 5 percent higher if the output of approved and authorized institutions were added to that of accredited institutions (California Postsecondary Education Commission, 1981, p. 182).

TABLE 5

ENGINEERING DEGREES AWARDED BY ABET-ACCREDITED INDEPENDENT CALIFORNIA COLLEGES AND UNIVERSITIES
1981

Institution	B.S.	M.S.	Engr.	Ph.D.
Cal Tech	120	106	1	42
Harvey Mudd	44	5		
Loyola Marymount	33	27		
Northrop	85	13		
Santa Clara	62	86		
Stanford	255	710	36	130
UOP	52			
USC	354	351	—	44
Total	1,005	1,298	37	216

Source: Doigan, 1982, p. 706.

ISSUES IN CALIFORNIA ENGINEERING AND COMPUTER SCIENCE EDUCATION

California leads all states in the total number of B.S., M.S., Ph.D., degrees awarded in engineering--during 1981, a record 9,366. New York produced the second greatest number of B.S. and engineering M.S. degrees, while Illinois and then New York produced the second and third greatest number of engineering Ph.Ds. Table 6 display the number and proportion of engineering degrees awarded in California compared to national totals. At this time, similar data are not available in the computer sciences.

TABLE 6

NUMBER AND PERCENT OF ENGINEERING DEGREES AWARDED BY CALIFORNIA INSTITUTIONS AND NATIONALLY 1981

Level	National Totals	California Totals	Percent Awarded by California Institutions
B.S.	62,935	5,684	9.0%
M.S.	17,643	3,088	17.5
Engr.	271	83	30.6
Ph.D.	2,841	511	18.0
Total	83,690	9,366	11.2%

Source: Doigan, 1982, pp. 705, 706.

Enrollment of Women and Minorities

Nationally, women graduates received 10 percent of the engineering B.S. degrees in 1981. Black and Hispanic graduates each received 2 percent.

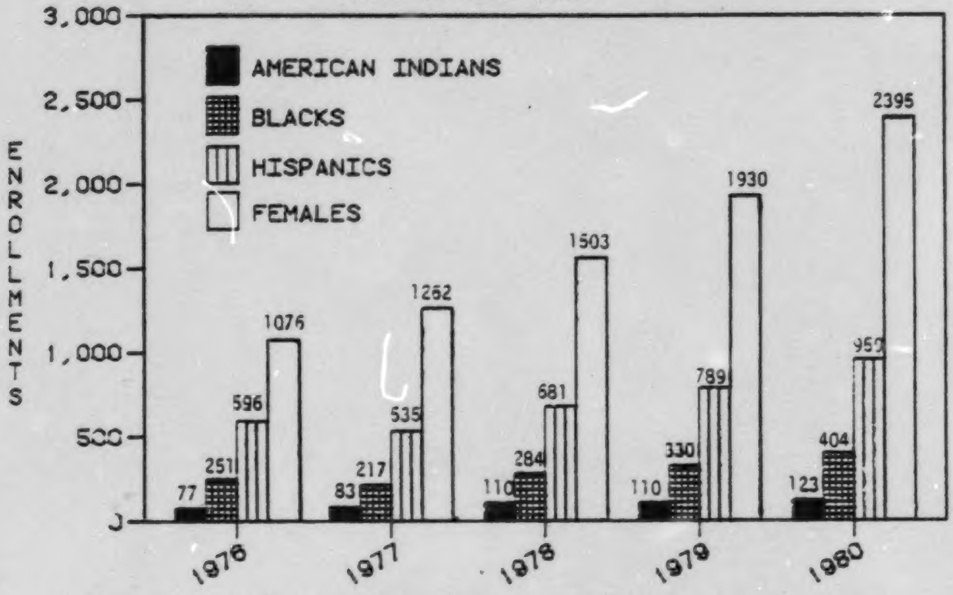
In California's public universities, the corresponding percentages were 9.4 for women, 1.0 for Blacks, and 3.8 for Hispanics. As Figure 21 shows, American Indians, Blacks, Hispanics, and women all showed gains in engineering enrollments during the 1976 to 1981 period, as did Asians and Filipinos. The five-year increases were 133 percent for women, 61 for Hispanics, 61 for Blacks, and 60 for American Indians, although the actual number of individuals was small. These gains were reflected in a decrease of 6 percent in the proportion of white males.

In computer science, women received 27.2 percent of the B.S. degrees awarded by California's public universities in 1981; Blacks received 1.0 percent; and Hispanics received 3.6 percent. Figure 22 shows enrollment gains for American Indians, Blacks, Hispanics, and women in computer science at all degree levels in both public segments over the five-year period. Enrollments of women increased by 219 percent, Hispanics by 418 percent, Blacks by 215 percent, and American Indians by 77 percent. In spite of these large percentage increases, the actual number of persons in each group was still small.

This topic is discussed further in Chapter Five, and more information about the enrollment of women and minorities in general appears in the Commission's recent report on Equal Educational Opportunity in California, Part IV (1982).

FIGURE 21

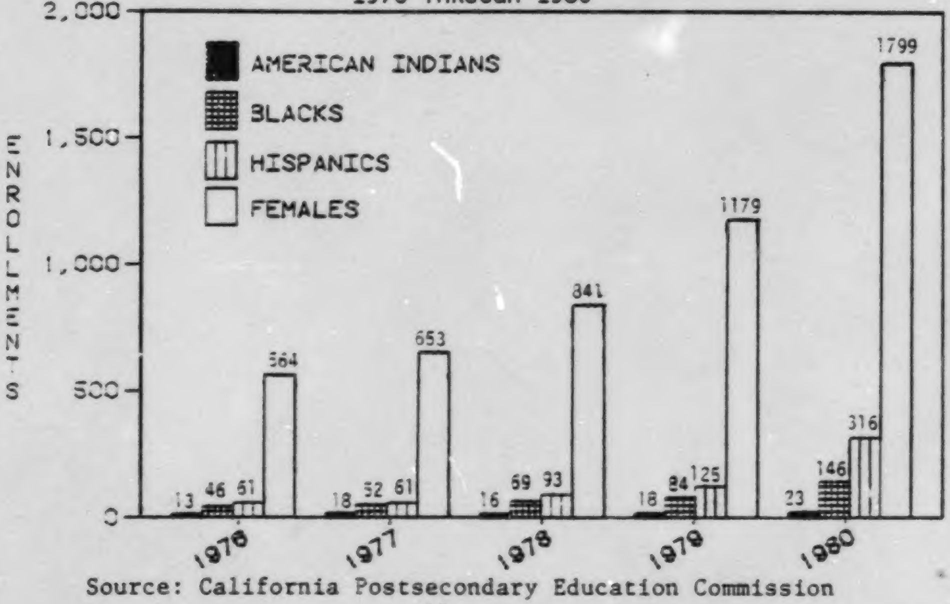
ENROLLMENTS IN ALL DEGREE LEVELS IN ENGINEERING
FOR SELECTED ETHNIC MINORITIES AND FEMALES
CALIFORNIA STATE UNIVERSITY AND UNIVERSITY OF CALIFORNIA
1976 THROUGH 1980



Source: California Postsecondary Education Commission

FIGURE 22

ENROLLMENTS IN ALL DEGREE LEVELS IN COMPUTER SCIENCE
FOR SELECTED ETHNIC MINORITIES AND FEMALES
CALIFORNIA STATE UNIVERSITY AND UNIVERSITY OF CALIFORNIA
1976 THROUGH 1980



Source: California Postsecondary Education Commission

Limits on Admission

It is becoming increasingly difficult to gain admission to engineering and computer science programs in California's public universities. As these programs increase in enrollment, a point is reached where faculty, equipment, space, and support are insufficient to accommodate more students. Student-faculty ratios and equipment problems are increasing. Unless the State provides more adequate resources, actions to hold enrollments at current levels or reduce them can be expected.

Impaction: Next fall, in the State University, the following declarations of impaction that impose supplemental admissions criteria will be in effect at the bachelor's level on these campuses:

Campus	Major
Fresno	All Engineering
Northridge	Computer Science General Engineering
Pomona	All Engineering Computer Science Engineering Technology
Sacramento	Computer Science Electrical and Electronic Engineering
San Jose	Aeronautics Chemical Engineering Civil Engineering Computer Science Engineering Electrical Engineering General Engineering Industrial and Systems Engineering Materials Engineering Mechanical Engineering
San Luis Obispo	Entire Campus All Engineering Computer Science

This leaves seven campuses in the State University system with engineering or computer science programs that have not been declared impacted--Chico, Fullerton, Humboldt, Long Beach, Los Angeles, San Diego, and San Francisco. Even those campuses that have not been declared impacted close applications for admission to engineering programs at an early date. As noted, the entire San Luis Obispo campus has been declared impacted for the past five years.

As of next fall, the following majors and degree levels will be declared impacted by the University of California:

Campus	Major	B.S.	M.S.	Ph.D.
Berkeley	Electrical Engineering-Computer Science	X	X	X
	Mechanical Engineering	X	X	X
Davis	All Engineering	X	X	X
	Computer Science	X	X	X
Irvine	Computer Science	X	X	
	Electrical Engineering	X		
	Civil Engineering	X		
	Mechanical Engineering	X		
Los Angeles	Engineering	X		
	Mathematics/Computer Science	X		
	Computer Science		X	X
	Electrical Engineering		X	X
Riverside	Pre-engineering (two-year program)			
San Diego	Computer Engineering	X		
	Computer Science	X		
	Electrical Engineering	X		
Santa Barbara	Electrical Engineering	X	X	X
	Mechanical Engineering	X		
	Chemical Engineering	X		
Santa Cruz	Computer/Information Sciences	X		

Some of these declarations of impaction date back to 1977.

Meaning of Impaction: When a program has been declared impacted both by campus and segmental officials, various supplemental admission criteria can be established. As the lower limit, four University and four State University campuses hold to the announced filing date for admission rigidly, if more students apply by that date than they can accommodate, they select students either in sequential order of receipt of applications or on the basis of high school GPA and SAT scores, although special provisions apply for minority and handicapped applicants on some campuses. Most of these campuses as well as the others that have declared impaction at the undergraduate level give preference to California residents to the point where essentially all nonresidents are excluded from admission to these programs.

At the most rigorous end of the supplemental admissions criteria spectrum, freshman applicants have in the past had to complete four years of high school mathematics through trigonometry, one year of physics, one year of chemistry, achieved a high school GPA of 3.6 or above, and earned a minimum score of 1,100 on the SAT. Next year, however, some campuses will raise these requirements to a 3.8 or 3.9 GPA, take honors courses into account, and increase the SAT score required.

Admission requirements for transfer students cover an equally wide range. As a minimum, many campuses require completion of two full years of pre-engineering and meeting the filing date, with some ranking transfer applications by GPA. At the rigorous end of the spectrum, others require specific courses, such as two years of calculus, 1 1/2 years of physics, one year of chemistry, and one introductory computer science course, plus a GPA of 3.3 or better.

Student Preparation

One can readily see that engineering programs are skimming off the cream of the crop of freshmen and transfer students. Yet, when asked by Commission staff about the preparation of entering engineering students, officials at seven CSU campuses and four UC campuses indicated that the preparation of high school graduates has declined during the past five years; those at six CSU and four UC campuses indicated that it has remained the same; and a representative of one campus (with highly selective supplemental admission criteria) stated that mathematics preparation had improved. With respect to high school preparation in science, respondents from 11 campuses indicated a decline, 10 stated it has remained the same, and one (at a highly selective campus) observed improvement. The same question was asked about the preparation of community college transfer students and five campuses indicated a decline in quality over the past five years; 16 indicated the quality has not changed; while none indicated an improvement. (This topic of students and their preparation is treated more fully in Chapter Five.)

Articulation of Community College and University-Level Programs

All but one of the UC and CSU respondents to the Commission's questionnaire regarding engineering indicated that the articulation agreement developed by the Engineering Liaison Committee of the Articulation Council has satisfactorily resolved the issue of community college engineering transfers. The dissenter indicated that the agreement is no longer working and needed to undergo review.

In contrast, most respondents for computer science indicated that computer science transfer is not working well at the statewide level. The Board of Directors of the Articulation Council is aware of the lack of coordination in computer science programs and may soon establish an Ad Hoc Liaison Committee on Computer Sciences to resolve the matter.

Placement of Graduates

An unusually high proportion of engineering and computer science graduates of California's public universities find employment in California. Among graduates of the State University over the past three years who obtained their position through the campus placement center, 91 percent of those with a bachelor's degree accepted employment in California, as did 92 percent of those at the master's level, according to data submitted by the campuses in response to the Commission's survey. For the University, 87 percent of the B.S. graduates, 83 percent of the M.S. graduates, and 77 percent of the Ph.D. graduates accepted positions in California. (Most bachelor's degree candidates utilize their campus placement center, but graduate students tend to obtain jobs through other means or return to previous employers.)

By comparison, Michigan State University reports that only 19 percent of its graduates took in-state jobs, and Georgia reports only a 24 percent retention rate. Ohio State, Purdue, and the University of Michigan report increasing numbers of graduates heading south and west ("Now, a Brain Drain from the Frost Belt," 1981, p. 87).

The soaring cost of relocating employees coupled with high interest rates and real estate prices makes it difficult for California high-technology industries to attract employees. The high percentage of California graduates who stay in California means that investments in engineering and computer science education in California's colleges and universities have immediate pay-off to California's economy. The point can be carried even further: Graduates educated in the Los Angeles-Orange County area tend to stay in that area, while the same is true for the Bay area. This fact should not be overlooked or treated lightly by industry or State government.

Cooperation with Secondary Schools and Industry

Most campuses are involved in cooperative efforts ranging from outreach programs with secondary schools to various programs with industry and government.

High School Outreach: Four University campuses and six State University campuses are participants in MESA, an acronym for "Mathematics, Engineering, and Science Achievement." The goal of MESA is to encourage talented minority-group students to take the necessary college-preparatory courses in high school in order to be able to major in engineering, physical sciences, or mathematics in college. MESA was initiated at Oakland Technical High School in 1970 with 25 students. Today there are 15 MESA centers statewide involving approximately 2,700 students at 90 high schools. MESA is grounded in providing tutorial services by volunteer faculty and college students, peer study groups, and summer enrichment programs. A "graduate" of MESA must complete four years of high school mathematics, three years of a laboratory science, and four years of English. Nearly 95 percent of the 471 graduates in 1980 enrolled in college, with about two-thirds enrolling in mathematics-based disciplines.

Three smaller outreach programs that use similar techniques are active on several campuses. One UC and one CSU campus are involved in the Minority Engineering Program; two UC and five CSU campuses operate programs sponsored partially by the Society for Women Engineers; and one CSU campus is involved in the Black Students in Engineering program.

Industry Programs: Twelve of the thirteen CSU campuses and all UC campuses report having formal internship programs with industry, including all types of design, manufacturing, and engineering companies. Seven CSU campuses and all UC campuses report having formal cooperative research activities with industry. Four UC campuses and four CSU campuses report having formal faculty exchange programs with industry. Such exchange programs have been promoted heavily by engineering societies, since there can be many advantages from having faculty members work in industry for a period of time while industrial engineers with special expertise engage in college teaching and research.

Continuing Education

While industry is lending support to campuses through the cooperative efforts described above, the campuses are also serving industry and government through on-site continuing education programs. Seven CSU campuses provide instruction at 15 different work sites, mostly at the graduate level, and four UC campuses provide instruction at 11 sites. Some offer only extension courses that terminate in a certificate, but others offer courses carrying full academic credit. Some campuses maintain live television links to industrial and military sites for both credit and noncredit courses. In addition, UC-Berkeley makes certain television courses available at off-campus sites for auditing purposes only.

Program Planning

New technologies demand new programs or new specialized courses within existing majors. Among technologies that are not currently covered but may become academically important during the next decade, nine campuses noted computer-aided design/computer-assisted manufacturing (CAD/CAM); seven mentioned computer networking; six noted robotics, five named software engineering; three identified very large scale integration (VLSI); and two each named artificial intelligence and bioengineering (and nine others identified satellite communications, mathematics modeling, ocean, data base management, computer-aided graphics, and human interface individually).

This list represents a challenge to systemwide and statewide planning. Certainly some campuses should be encouraged to develop degree programs around certain of these new technologies, particularly CAD/CAM and robotics, but which ones? California cannot afford nor should it allow all campuses to move to develop these new majors, although some introductory courses may be necessary on most campuses. Early identification of the best locations for special high-cost majors is essential. Adequate support for facilities and equipment can then be directed toward these designated centers rather than fragmenting resources among all campuses with none having enough to provide excellence in the new specialty.

60

CONCLUSION

Enrollments in California's engineering and computer science programs appear to be keeping pace with national trends, but most of California's public universities have declared many of their undergraduate engineering and computer science programs impacted largely due to lack of faculty and equipment. As a result, they have become more selective in freshman and transfer student admissions to these programs than to non-impacted programs, and their enrollments in these programs may not keep up with demand as a result.

One particularly noteworthy aspect of California's public higher education in engineering and computer science is that a vast majority of its graduates remain in California and contribute directly to its high-technology industries.

The University and State University have developed numerous cooperative arrangements with high schools and industry, but a curricular challenge lies ahead for academic planners. New technologies must be introduced into engineering and computer science programs. This is the time to determine the need for these new specialties, their distribution, and campus location.

CHAPTER THREE

FACULTY

As of January 1981, a total of 33,859 full-time faculty members were teaching engineering or computer science in American colleges and universities--26,992 of them in engineering, and 6,867 in computer science. Their numbers had increased 25.1 percent over the previous five years, with engineering faculty growing 17.7 percent from 22,924, and computer science faculty jumping 68.6 percent from 4,133. Women among engineering faculty increased their numbers 78.6 percent --from 449 to 802, while in computer science they jumped 130.9 percent--from 482 to 1,113, although they still constituted only 5.7 percent of the full-time faculty members ("Fact-File: Engineers and Scientists at Colleges," 1982, p. 10).

Despite these increased numbers of faculty, faculty shortages plague engineering and computer science programs, both nationally and in California. This chapter reviews the extent of these shortages in the nation at large and then in the California State University and the University of California, as well as issues of faculty recruitment, turnover, and salaries associated with them.

THE NATIONAL SHORTAGE OF ENGINEERING FACULTY

At least half a dozen studies conducted to determine the extent of the faculty shortage in engineering have placed the magnitude of the shortage of full-time faculty at between 10 and 15 percent. For example, the latest and most definitive, undertaken by the American Council on Education under sponsorship of the National Science Foundation, the Department of Education, and the National Endowment for the Humanities, found that 10 percent of full-time engineering faculty positions were unfilled during Fall 1980 in the nation's 244 institutions with accredited engineering programs (Atelsek and Gomberg, 1981). Among its other findings:

- The highest proportion of vacancies--16 percent--was in computer engineering, followed by electrical engineering at 13.4 percent. The lowest vacancy rate was in aeronautical engineering at 4 percent.

- Almost 400 full-time engineering faculty members, representing 2.7 percent of the permanent staff, left academia for industry during the 1980-81 year.

- More than three-fourths of the engineering deans cited superior industrial "salaries and financial benefits" as the chief reason that engineering faculty leave.

- A high percentage of the deans believe the quality of both education and research has suffered as a result of the faculty problem. Eighty-two percent detected a decrease in the quality of instruction, and 75 percent saw a decline in the quality of research.

- Fifteen percent of the deans pegged the decline in the number of engineering doctorates as the major problem.

- Nearly one-fourth of full-time junior engineering faculty received their bachelor's degrees outside the United States, indicating that "engineers from other countries have prevented shortages from becoming even more severe."

In a parallel study, John Kemper, Dean of Engineering at the University of California, Davis, found that the 244 institutions had a total of 1,800 unfilled engineering faculty positions in 1980 and that 335 more vacancies will occur each year between 1981 and 1985 because of retirements and an additional 380 each year because of increased enrollments (1980). He has calculated that for the ten-year period of 1981 to 1990, 7,525 vacancies will occur because of both retirements and expansion--an average of 750 per year. If the existing backlog of vacancies were to be reduced over the same ten-year period at 180 per year, an average of 930 persons with engineering doctorates would be needed each year for academic positions alone--and this number does not include the faculty needed to replace those who resign each year to enter business, industry, or government. This need for faculty comes at a time when the number of doctorates awarded in engineering is at a low point--approximately 2,800 per year, with 1,760 of them U.S. citizens and 1,040 of them foreign nationals. Two-thirds of each year's doctorates are employed by industry, and only about one-fourth are both interested and qualified for teaching and research in an academic environment. Hence, the current domestic supply of engineering faculty is only 440 per year, far short of the minimum number of 930 needed each year.

In a similar analysis (1981), Daniel Drucker estimates that of the approximately 2,800 engineering doctorates granted per year, no more than one-third are intellectually qualified for faculty positions, and only one-third of these would choose academic over industrial positions, even if University salary scales were returned to the same ratio of industrial salaries as in the 1960s and if all foreign nationals remained in this country. His calculations would indicate a supply of only 300 new faculty a year, even with these unlikely prospects.

Because the number of full-time faculty has not kept pace with increases in enrollments, overcrowding of class sections and laboratories and the hiring of large numbers of part-time faculty have become common, both of which have resulted in an increasingly overworked full-time faculty and reduced program quality. Commenting on the ACE findings, Engineering Education News stated:

> An overworked and underpaid faculty is not a happy faculty, particularly when lucrative salaries, excellent benefits and first-rate laboratory equipment await almost any Ph.D. engineer who merely glances at an industrial recruiter . . .
>
> As the faculty shortage worsens, life in academe becomes even less attractive. Fewer hands and minds must do more work, creating a vicious cycle. Ultimately schools suffer a loss of quality (1982c, p. 1).

Faculty who are leaving the teaching of engineering for other employment are not merely the untenured and inexperienced. In a survey of engineers who had left academia, Eisenberg and Galanti found (1981, p. 701):

> The majority of the respondents were of a relatively mature age level, with 95 percent over age 30, 47 percent over age 39, and a mean age for the group of 39.9 years . . . . [O]ver half of the respondents had been promoted or tenured, or both. The personal profiles obtained from the survey appear to refute the generally widespread notion that only young, inexperienced faculty are leaving academia (underlining added for emphasis).

Even nationally prestigious institutions are short of faculty:

- Massachusetts Institute of Technology has been unable to fill all its faculty positions in such sought-after fields as microelectronics and computer engineering.

- Cornell University's College of Engineering has had some graduate seminars expand to 50 students from 20 students in less than a decade, while seven of the school's 42 full-time faculty positions in electrical engineering remain vacant. ("Surge in Engineering Enrollments . . .," 1981).

- At the University of Michigan, the total faculty has declined by 45 members while enrollments steadily climbed during the last seven years (Peterson, 1982, p. 25).

- At the University of Illinois, Champaign-Urbana, engineering enrollments are being reduced by 20 percent in order to maintain quality by relieving the pressure on overworked faculty and crowded laboratories. Even students who score in the 97th percentile on entrance exams are not admitted (Samuelson, 1981).

Fred Landis, who has worked extensively on the use of engineers in industry and on engineering manpower projections, foresees increasing difficulty in attracting faculty from a shrinking supply of doctoral graduates. He has concluded that in the short run the nation's capacity to produce engineers may reach an upper limit of 70,000 to 80,000 per year, but that over a longer period, this rate cannot be maintained because of overstretched resources and will drop to between 50,000 to 60,000 per year (1981, p. 788). And Daniel Drucker of the University of Illinois, the president of the American Society for Engineering Education has stated, "We're only fit to turn out 40,000 (engineering) B.S. graduates a year . . . . We can maintain quality only by shrinking in size" (*Engineering Education News*, March 1982b, p. 4).

CALIFORNIA STATE UNIVERSITY

The California State University employs 721 full-time engineering and computer science faculty on its 13 campuses that offer engineering. Of these faculty members, 403 are professors, 172 are associate professors, 56 are assistant professors, 86 are lecturers, and 4 are instructors. Women comprise 3.5 percent of these full-time faculty, and non-citizens constitute 8.4 percent.

In order to meet its instructional load in engineering and computer science, the State University also employs 726 part-time faculty, equivalent to 221.8 full-time equivalent positions, of whom 5.6 percent are women and 13.0 percent are non-citizens. If the State University were able to compete effectively in the faculty recruitment marketplace, it would fill 65 percent or 472 of these part-time-equivalent positions with full-time faculty. This would leave 77 full-time positions reserved to employ some 320 individuals as part-time faculty to capitalize on their special expertise and to retain flexibility as student demands and interests change.

Resignations and Retirements

Within the past three years, 37 tenured and 37 non-tenured faculty have resigned. Thirty-nine were hired by industry, 32 accepted positions at other universities, and 4 sought government or other employment. Thus industry is the major competitor for State University faculty, followed closely by other universities.

The retirement rate for full-time faculty has been about normal for the past three years, but is expected to double during 1982-1986, and more than double during the years 1986-1990.

Faculty Recruitment

The recruitment picture for the State University is very discouraging:

- One large campus has attempted to fill 20 tenure-track positions in engineering over the past three years. From a total of 215 applications, it made 22 offers--but 10 were rejected.

- To fill three assistant professor positions, 11 associate professor positions, and four professor positions in computer science, another large campus has made a total of 15 offers over the past three years, resulting in only three acceptances, two of whom have subsequently resigned. This campus has found recent changes by the Trustees to hire assistant professors at associate professor salaries useless because salaries are still far below the marketplace.

- After three years of intensive recruiting, a third large program has fewer full-time faculty than in 1979, due to inadequate salaries and high housing costs.

- After recruiting for 31 positions over the past three years (including duplicates that could not be filled), a fourth campus has made seven appointments, but during this time seven more faculty departed. Many of its faculty are engaged in consulting because, as one of them stated, "we have to consult to support our teaching habit."

- A fifth campus reports filling 12 of 20 positions in three years. A sixth has made three offers for five vacancies in the past three years and filled only one. A seventh has filled its computer science vacancies despite a 50 percent rejection rate to offers, but has found only nine faculty for 16 vacant engineering positions--and one of the nine resigned after one semester.

- An eighth campus with five vacancies received large numbers of applications from foreign nationals but only a few from U.S. citizens and hardly any from women or minorities. A ninth, located in a metropolitan area, has had applications only from aliens who are in the U.S. on student visas, and cannot attract citizens to apply because of low salaries. And a tenth, also in a metropolitan setting, receives applications primarily from foreign nationals with no industrial experience and has made 14 offers in the past three years for four acceptances and 10 rejections.

To overcome these recruitment problems, the Trustees of the State University have adopted the policy that from April 1, 1982, until June 30, 1983, new faculty in engineering, computer sciences, and business administration may be hired at steps 1 to 5 of the associate professor level, where necessary. Yet even this temporary action places the State University at a level attempting to recruit new Ph.D.s in engineering at $700 to $9,582 a year below the beginning average industrial salary for Ph.D.s, assuming summer employment, based on salary offers at the 50th and 90th percentile to Ph.D.s reported in Table 4 on page 19 above. In fact, this new salary range competes mainly with salaries offered to graduates with B.S. degrees and inexperienced M.S.-degree holders.

In response to the Commission survey, deans and directors reported that program quality is being weakened because of the faculty shortage. When asked to identify the three most significant problems of their programs in priority order, they listed:

1. Lack of full-time faculty.
2. Need for new equipment.
3. Need for a reasonable long-range equipment replacement program.

They indicate that while students are receiving good instruction in theory, their classes and laboratory groups are too large and new state-of-the-art techniques are not included in laboratories because of obsolete equipment. Students are taking longer to graduate because needed class sections are closed. One dean acknowledged that because of low salaries he was not always able to select the best qualified faculty and that the advising load of full-time faculty is too heavy for adequate advice because of the high number of part-time instructors.

Most of the deans and directors suggested a differentiated salary scale in the neighborhood of $10,000 per year as a solution to the faculty shortage, and many proposed reduced teaching loads as an alternative, with funds for faculty renewal mentioned in two instances.

UNIVERSITY OF CALIFORNIA

The University currently has 529.33 full-time engineering and computer science faculty, including 83 assistant professors, 81 associate professors, 356.33 professors, and 9 lecturers. One and one-half percent of these full-time faculty are women, while 20 percent are non-U.S. citizens. In order to meet its instructional load, the University employs 306.66 part-time instructors representing the equivalent of 99.06 full-time faculty. Four percent of these instructors are women and 14 percent are non-citizens.*

The employment of some part-time faculty is of course desirable: it not only augments full-time faculty with persons having special expertise, but it also provides some flexibility for the peaks and valleys of cyclical enrollment patterns. Yet according to the respondents to the Commission's survey of engineering deans, two-thirds or 204 of the part-time positions would be filled with full-time faculty if qualified candidates could be hired.

Resignations and Retirements

During the past three years, 46 faculty have resigned--23 with tenure and another 23 without tenure. Seventeen of them accepted positions at other universities while 24 accepted positions in industry, and the remaining five went to government or some other unspecified position. In total, the turnover rate is running about 9 percent over three years (excluding retirement), with industry being the major beneficiary of departing faculty and with administrative officials concerned about increased turnover in the future.

Twenty-two full-time faculty retired during the past three years, for an annual average rate of about 1.4 percent. Two percent of the current faculty are expected to retire before 1986, and 7 percent more between 1986 and 1990.

The retirement rates observed for the last three and projected for the next four years are about normal for university faculty nationally; beginning in 1986, however, the rate will be nearly double what has been considered normal in higher education. This rate change has been anticipated for some time, since many faculty who were hired during the growth period of the 1950s and '60s will reach retirement age during the latter part of the '80s. This will intensify recruitment of new faculty, but, at the same time, it may allow for internal readjustments in faculty distribution among disciplines not otherwise easily achieved.

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*One of the eight UC campuses surveyed did not report the number of positions occupied by non-citizens.

Faculty Recruitment

In spite of its prestige and other positive factors, the University's recruitment efforts have not been fully successful:

- For example, one campus has been able to fill only nine of its 12 vacant full-time engineering positions over the past three years. The number of applicants for each position has averaged around 50, with a low of 11 and a high of 70. One position that has been vacant for over three years continues unfilled due to the lack of qualified candidates.

- A second campus reports receiving about 100 applications for each of nine positions over the past three years. Of these applications, only about five percent were qualified. Its acceptance rate for its offers is running about 50 percent.

- A third reports filling only eight of 15 positions vacant during the past three years with full-time faculty because of an insufficient number of qualified applicants. It made 11 offers to fill the positions, but three of its offers were rejected.

- A fourth reports filling eight positions but having 11 current openings. It suffered six rejections, but without the new salary schedule adopted by the Regents for engineering and business administration, this number most likely would have been larger.

- A fifth summarized its recruitment situation as follows: In searching for 12 positions over the last three years, found 95 qualified candidates out of 627 applicants; interviewed 74 at national meetings, during vacation or on campus; and made 14 offers, of which 10 were accepted and four were rejected, leaving the campus a net shortage of two faculty positions.

- The sixth campus in 1979-80 received 48 applications in computer sciences and made two appointments. In 1980-81, it received 66 applications for a junior faculty vacancy but made no offers because of the low quality of applicants. That year, it made one offer for a senior-level faculty vacancy, but it was declined. In 1981-82, 65 applications were received, one offer was declined, and one is still outstanding.

The revised salary schedule for professors in business/management and engineering adopted by the Regents for implementation in 1982-83 represents new scales that increase salaries for all professorial ranks, with the highest percentage increases, at amounts from 24.4 to 33.8 percent, going to assistant and associate professors. Nonetheless, even adding in summer employment, the schedule is still $5,000 to $9,000 below industrial competition at the first-step assistant professor level. And because the new schedule has only four steps in the assistant professor range, appointments at the top of the range will still be $1,000 to $2,000 below beginning industrial salaries at the 90th percentile of Ph.D. salaries in Table 4 on page 19.

In response to Commission questions about the effects that faculty and equipment shortages are having on the quality of programs and on students, three deans indicated that program quality has been affected, and all commented that students were being affected by oversubscribed classes, resulting in delays in obtaining degrees; large laboratory groups, which tend to make students spectators rather than active participants in experiments; and decreased amounts of time for individual consultations with students. One dean commented that instruction by temporary faculty is inferior to that of regular faculty. Another felt that the most serious consequence is that many qualified students cannot gain admission because of the high GPA scores used to limit enrollments--3.9 for high school graduates, and 3.3 for community college transfers. A third hopes to initiate a computer literacy requirement but has been unable to implement it yet because only one-third of the pre-enrolled students can thus far be accommodated.

CONCLUSION

Between 1976 and 1981, engineering and computer science faculty increased nationally by 25.1 percent, while bachelor's degrees increased 88 percent. The resulting shortages in engineering and computer science faculty in the public institutions in California parallel those of major institutions nationally.

Faculty salaries remain non-competitive, and both the University and State University are losing tenured as well as non-tenured faculty to industry. Faculty recruitment remains difficult, even though the Regents and the Trustees have adjusted their salary scales for new hires. Faculty salaries in high-technology fields are too low to compete in the affirmative action market for the limited number of women or minorities available to teach engineering or computer science in the University or State University.

Many new faculty have obtained their early training outside the United States.

While all campuses have consistently used part-time faculty to add special expertise to their teaching staff, this is no longer the main rationale for use of part-time faculty. More and more part-time faculty are being used because qualified full-time faculty cannot be hired. On some campuses, 40 percent of engineering and computer science classes are being taught by part-time faculty. Both the literature and opinions from the field agree that in many instances, the quality of instruction has declined. These part-time instructors throw a heavier load of counseling and individualized attention onto full-time faculty, which in turn reduces morale.

Recruiting more full-time faculty in the future will not be easy. At the same time that larger numbers of older faculty will be retiring from universities during the 1980s, large numbers of older employees will be retiring from industry, thereby increasing the competition for the limited number of Ph.D.s available. As will be noted in Chapter Seven, California will need to take further steps than the recent salary increases for technological faculty if it is to remain at the forefront of engineering and computer science education in the future.

CHAPTER FOUR

EQUIPMENT AND FACILITIES

All recent reports on engineering education, regardless of which side they take on the issue of supply and demand, comment on the problem of obsolete teaching and research equipment. For instance, *Science and Engineering Education for the 1980s and Beyond*, from the National Science Foundation and the Department of Education, states that besides the faculty shortage,

> an important additional problem in engineering education is a severe lack of the equipment required for instructional purposes at the undergraduate level. During the past decade, computer-aided design and computer-assisted manufacturing methods have provided important gains in productivity for some large companies in this country. The apparatus required to teach these methods to students, however, is generally unavailable in engineering schools. Consequently, a good deal of the instruction being offered may in fact be obsolete (1980, p. 9).

And the Task Force on Engineering Education of the National Academy of Engineering observes (1980, p. 14):

> The problem has been exacerbated by the acceleration of technological progress during the last twenty years, increases in the sophistication of the laboratory equipment required, and increases in costs. By in large, colleges have been unable to cope with spiralling costs. The result, particularly with respect to teaching, has been a growing gap between the equipment that students use in their instructional laboratories and the kind of equipment that they encounter in industry. Such gaps have always existed, but there is now strong evidence that the gap is becoming so large that the ability of engineering colleges to train students adequately for the future is seriously threatened.
>
> Unless the trends change, engineering colleges will not be able to provide adequate training in many of the new, most important technologies without substantial help.

An editorial in *Science* states, "The increased complexity of modern instrumentation plus inflation in equipment costs has overextended college budgets available for equipment and facilities. Quality engineering education requires modern facilities" (Willenbrock, 1981, p. 1319).

A substantial portion of the physical facilities and equipment in engineering education as well as other fields were acquired in the 1950s and '60s. California colleges and universities received more than $1 billion in facilities and equipment through the Coordinating Council for Higher Education Titles VI and VII of the federal Higher Education Facilities Act of 1965, but these programs were discontinued in the early 1970s. The states have done little to keep facilities and equipment up to date since then, and institutions have not provided for either amortization or adequate maintenance and repair ("Crisis in Engineering Education," 1981, p. 63). Donald Glower of Ohio State University estimates that the underinvestment in engineering facilities, equipment, and instrumentation during the 1970s has now resulted in an accumulated shortfall of about $750 million in U.S. engineering schools (p. 36).

The lack of modern facilities and equipment has contributed to the shortage of engineering faculty. The National Science Foundation and Department of Education found that:

> Lack of access to state-of-the-art research facilities for university faculty and graduate students decreases the attractiveness of academic careers and contributes to the engineering and computer profession faculty shortage problem . . . . The noncompetitiveness of academic salaries, while an obvious contributing factor to the engineering and computer professional faculty problem, may not be of overriding importance. University faculty have traditionally been willing to forego higher salaries outside of academia in exchange for opportunities to conduct research and work with good graduate students in a university setting. However, many observers believe that difficulties in obtaining research support, lack of stability in Federal research support and, most importantly, the existence of greatly superior research facilities in industry have all contributed to the decreasing attractiveness of academic careers (1980, p. 36).

The American Electronics Association highlights several examples of outdated equipment (1981a, pp. 16-18):

- John Fluke, president of John Fluke Manufacturing and a member of AEA's Blue Ribbon Committee on Engineering Education found recently that his alma mater was still using some of the same equipment he had trained on fifty years ago.

- The American Society for Engineering Education (ASEE) has found that teaching equipment in most university engineering laboratories is 20 to 30 years old and equipment to teach new "growth technologies" such as computer-aided design (CAD) and computer-assisted manufacturing (CAM) is almost non-existent.

- Few colleges can afford CAD/CAM and integrated circuit technology, consequently their students have been graduating without training in these areas.

- The Association of Independent Colleges has estimated that, on the basis of a 6.5-year average as the useful life of instructional equipment, $1,500 per year will be needed for each engineering baccalaureate degree granted to keep equipment up to date.

- ASEE estimates that it will take $40 million per year to update laboratory equipment and to modernize classrooms in the nation's accredited engineering schools.

The Engineers' Council for Professional Development (predecessor to the Accreditation Board for Engineering and Technology) calculated several years ago that the new equipment needed by an engineering college costs $100,000 per year per program plus $150 per student per year. Based on this estimate, the Task Force on Engineering Education of the National Academy of Engineering claims that a national program with 50,000 degrees per year would cost at least $200 million per year. "Engineering colleges have nothing close to this amount of money at their disposal," says the Task Force. "The integrated backlog of the shortage that is being produced is now enormous and growing" (1980, p. 15).

Paul Gray, president of the Massachusetts Institute of Technology, puts the capital cost of remodeled facilities and new equipment at approximately $300,000 to $400,000 per graduate and says, "If we are going to make any substantial increase in capacity and size (of programs), those costs are going to have to be met in some way" ("Engineering Education: Coping with the Crisis," 1981, p. 65). And Stephen Kahne of the National Science Foundation estimates that nationwide $1.5 billion is needed to upgrade undergraduate facilities and equipment alone.

CALIFORNIA STATE UNIVERSITY

As noted in the previous chapter, the deans and directors of the State University's engineering and computer science programs identify inadequate equipment and facilities as second only to insufficient faculty among the most serious problems of their programs. The State University has not published any recent reports of its instructional equipment including dates of acquisition, rate of obsolescence, and other pertinent data, but it is generally known that its 19 campuses face crucial equipment replacement problems.

Like most colleges and universities, the State University acquired a major portion of its equipment in the 1950s and 1960s as part of an ambitious capital outlay program, and officials in the Chancellor's Office place the total replacement value of instructional equipment near $250 million.

Annual allocations to the State University for replacement of instructional equipment since 1976 are presented in Table 7. According to the Chancellor's Office, the highest of these figures --$4,159,750 in 1981-82--provided funding at a level that was approximately 1.7 percent of the total replacement cost of the system's instructional equipment inventory at current dollar levels. This level of replacement requires an average 59-year life cycle for equipment--an unrealistic requirement, by any known method of determination. Yet even this small amount of funding for replacement has been available only since 1976.

Of the $3 million proposed for the State University system under Governor Brown's "Investment in People" initiative, it plans to use $1 million for replacement equipment. The equipment needs of the State University will remain high, nonetheless and a long-term solution is not yet in sight. Technological progress, the escalating cost of new equipment, and outmoded equipment that is no longer relevant all limit its instructional programs. Courses designed around obsolete equipment are of less than antiquarian value to students and of even less value to their prospective employers.

TABLE 7

INSTRUCTIONAL EQUIPMENT REPLACEMENT BUDGET CALIFORNIA STATE UNIVERSITY, 1976-77 TO 1981-82

Year	Amount
1976-77	$3,198,031
1977-78	3,389,913
1978-79	3,389,927
1979-80	3,772,973
1980-81	3,961,622
1981-82	4,159,750

Source: California Postsecondary Education Commission.

UNIVERSITY OF CALIFORNIA

In 1975, the University of California undertook a thorough study of its equipment replacement problems. Howard Booth developed a computerized analysis of all its inventoried equipment classified as "General Equipment"--a category containing approximately two-thirds of all equipment on inventory--but excluding equipment of the University's medical and veterinary medical hospitals and clinics. His analysis demonstrated the serious equipment problem facing the University. It did not estimate the amount of money needed to purchase new state-of-the-art equipment, but it concluded that inadequate equipment was having a significant impact on the quality and integrity of academic programs.

Booth's study found nearly a fourth of all equipment obsolete, 5 percent of the remaining equipment becoming obsolete annually, and available funds inadequate for replacing obsolete equipment. It found that at the close of the 1973-74 fiscal year, the acquisition value of all General Equipment stood at $274,454,781. When adjusted for inflation, its value was $329,709,612. Approximately 23 percent of all this equipment (or $76,767,066 worth) was obsolete, according to government and industry standards for similar types of equipment. Of all remaining equipment, $14,467,682 worth, or approximately 5 percent, became obsolete during the following fiscal year. The depreciation (straight-line depreciation to salvage value) that accrued to all functional equipment during the same period amounted to $17,341,73[illegible].

Obsolescence of equipment does not occur at a uniform or fixed annual rate because of the variations in time when equipment was purchased. For example, at the University about 10 percent of its general equipment was acquired prior to 1958, 18 percent was added during the years 1959 to 1963, 32 percent was added from 1964 to 1968, and 40 percent was added during the years 1969 to 1973. Nevertheless, State General Fund appropriations since 1976 have been insufficient to replace obsolete equipment or to purchase equipment for new technologies. Table 8 traces these appropriations over the past six years. These appropriations average approximately $6.9 million per year, or only about 40 percent of what has been needed to keep the University's equipment up to date. The questionnaire used in this study indicates that about $7.5 million is needed annually in engineering and computer sciences alone for replacing obsolete equipment. Another $11.8 million is needed annually for modernization of engineering and computer science programs by incorporating state-of-the-art equipment in such new technologies as robotics, computer-aided design, computer-assisted manufacturing, integrated circuit technology, and microcomputers.

TABLE 8

INSTRUCTIONAL EQUIPMENT REPLACEMENT BUDGET UNIVERSITY OF CALIFORNIA, 1976-77 TO 1981-82

Year	Amount (actual)
1976-77	$4,425,000
1977-78	6,904,300
1978-79	3,168,300
1979-80	7,396,600
1980-81	9,240,000
1981-82	10,165,000 (estimated)

Source: California Postsecondary Education Commission

In order to satisfy some of its urgent equipment needs, the University has proposed that $3.5 million of the proposed allocation of $4 million under Governor Brown's "Investment in People" initiative be used to purchase technological state-of-the-art equipment for its Berkeley, Davis, Irvine, San Diego, and Santa Barbara campuses where its equipment needs are most critical. The balance of the funds are proposed to be used to increase retention of women and ethnic minorities in engineering.

CONCLUSION

Modern instructional and research equipment is more essential today to engineering education than it has been at any time in the past. It has become the foundation for new technological skills and professional techniques. Yet, university equipment purchased largely during the 1950s and 1960s is increasingly obsolete, and universities are unable to deal with obsolescence in the conventional manner. Neither the University of California, the California State University, nor, for that matter, the California Community Colleges are permitted to establish a depreciation reserve as would a business organization. They must annually request replacement funds from the State. They are not permitted to replace equipment through the capital budget but only new equipment for the purpose of expansion. New equipment for the purpose of improvement or replacement may only be obtained through the operating budget. At no time during the last decade have equipment funds in the University's or State University's operating budget equaled or exceeded the rate at which equipment was becoming functionally obsolete, let alone technologically antiquated.

A greater quantity of equipment will be necessary in the future to maintain present levels of program quality. Where equipment acquisition is deferred, quality of instruction will decline, since obsolete equipment results in courses being designed around outmoded techniques and reduces the amount of subject matter that can be covered. Limited equipment reduces the size of classes, wears out at a faster rate, and prevents full participation by all students. The problem is becoming so serious that the integrity of many current courses is questionable.

CHAPTER FIVE

STUDENTS AND THEIR PREPARATION

Most engineering and computer science students are of traditional college age rather than older students, and this fact has double implications for program planners: (1) the numbers of traditional college-age students will drop considerably during the 1980s even if enrollments of older students increase; and (2) younger students have had less adequate high school preparation in mathematics and science than their predecessors.

THE DECLINE IN STUDENT NUMBERS

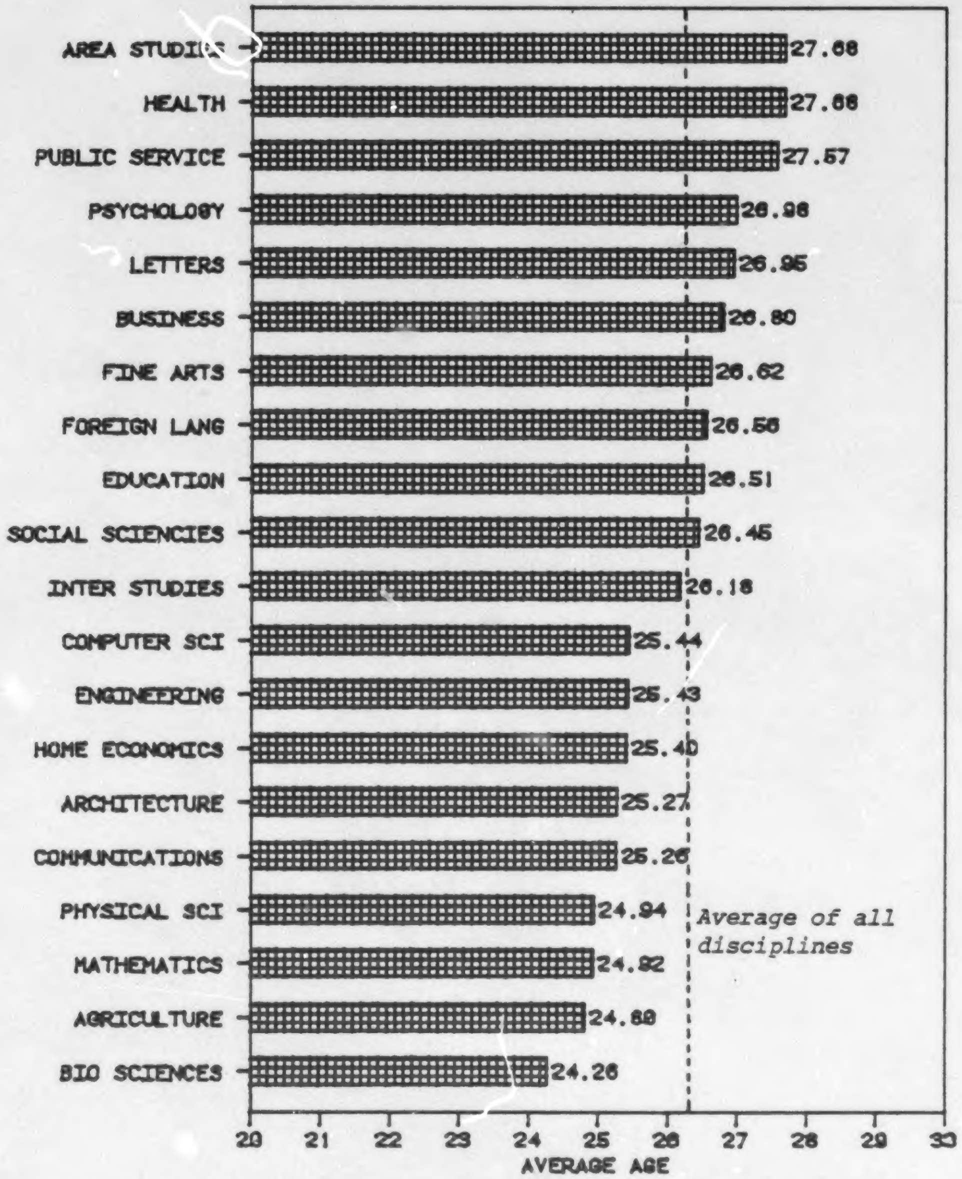
Figure 23 shows the average age of bachelor's degree recipients at both the University and State University. As can be seen, those programs that require mathematics and science skills such as computer science, engineering, architecture, physical science, mathematics, and biological science are among those pursued by traditional college-age students: They are not appealing majors for reentry students. All of these programs graduate students below the median age of all University and State University bachelor's degree recipients. Clearly, the major pool of undergraduate engineering and computer science students thus comes from the under-24-year-old age group.

Yet the U.S. Census Bureau calculates that enrollments of the under-24-year-old age group will decline by 803,000 or 11.0 percent by 1990, even if colleges and universities increase their enrollment of students over 25 years old (Table 9). Thus engineering and computer science enrollments will be severely impacted by the projected decline of 803,000 in the under-24 age group.

The absolute number of high school graduates in 1985--the low point in the population curve for this age group--will be 15 percent lower than in 1975. Thus, even if the supply of engineering and computer science graduates should catch up with demand by the mid-1980s, the surplus would probably be short lived because of the forthcoming decline in the numbers of students thereafter. In order to keep pace with the demand for high technology manpower, the potential pool of applicants to engineering and computer science programs will have to extend beyond its traditional constituency of white males.

FIGURE 23

AVERAGE AGE OF BACCALAUREATE DEGREE RECIPIENTS AT THE UNIVERSITY OF CALIFORNIA AND THE CALIFORNIA STATE UNIVERSITY, 1976-77 TO 1979-80



Source: California Postsecondary Education Commission

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TABLE 9

PROJECTED CHANGES IN ENROLLMENT OF TRADITIONAL COLLEGE-AGE AND OLDER STUDENTS, 1979-1990

Age group	Estimated enrollment in 1979	Proportion of population in 1979	Projected population in 1990	Projected enrollment in 1990	11-year change
14 through 17	311,000	1.9%	12,770,000	243,000	− 68,000
18 and 19	2,844,000	34.6%	7,196,000	2,488,000	−356,000
20 and 21	2,353,000	29.1%	7,311,000	2,128,000	−225,000
22 through 24	1,794,000	15.4%	10,641,000	1,638,000	−156,000
Total, 14 through 24	7,302,000	16.6%	37,917,000	6,499,000	−803,000
25 through 29	1,679,000	9.3%	20,169,000	1,876,000	+197,000
30 through 34	986,000	6.1%	20,917,000	1,276,000	+290,000
35 through 39	566,000	4.2%	19,261,000	809,000	+243,000
40 through 44	330,000	2.9%	17,331,000	503,000	+173,000
45 through 49	223,000	2.0%	13,888,000	278,000	+ 55,000
50 through 54	139,000	1.2%	11,422,000	137,000	− 2,000
55 through 64	111,000	0.5%	20,776,000	104,000	− 7,000
Total, 25 through 64	4,044,000	3.2%	123,766,000	4,983,000	+939,000
Total, 14 through 64	11,346,000	7.7%	161,683,000	11,482,000	+136,000

Source: "Fact File: The Enrollment Boom Among Older Americans," The Chronicle of Higher Education, May 4, 1980, reproducing data from "School Enrollment--Social and Economic Characteristics of Students," Current Population Reports Series P-20, No. 360, October 1979, of the U.S. Bureau of the Census.

THE DECLINE OF STUDENT PREPARATION

Since 18-to-24-year-old students by and large comprise the potential student body for engineering and computer science programs in the University and State University, the characteristics of recent California high school graduates offer evidence about the preparation of applicants to these programs. California has received a generous amount of adverse publicity about its inability to enlist high school students in solid academic courses like mathematics, science, and English. For example, among California high school students taking the Scholastic Aptitude Tests, fewer have taken as many years of study in key academic disciplines except in foreign languages than students elsewhere. Only 15 percent of these young men in California and 7 percent of these young women in California have taken three or more years of science, compared to 30 percent of the young men and 16 percent of the young women nationally. Only 55 percent of California's male students and 35 percent of women take four or more years of mathematics in high school, compared to 66 percent of males and 48 percent of females nationally. Michael Krist, professor of education at Stanford University and former president of the State Board of Education, attributes these conditions to three factors: (1) the State University counts subjects equally, making no distinction between a student who takes English and one who takes photography; (2) students avoid higher level courses for fear their GPA will fall; and (3) many students attend school for only half a day, working 20 or more hours a week. Mr. Krist said, "It's surprising and alarming to see students in the world's most advanced technological state taking courses more appropriate for a relatively backward region" ("California Students Avoiding the Tough Subjects," 1980, p. 1).

Initial drafts of the Curriculum Review Handbook (1981) prepared by the California State Department of Education included the following observations about student preparation:

Decline in Achievement

- California Assessment Program (CAP) reports that the 0.1 percent loss in reading scores of twelfth grade students in 1980 continues an eight-year decline for the state's graduating seniors.

- College Entrance Examination Board reported that the 1980 SAT scores in verbal and math skills of California's high school students continued the fourteen-year decline. The 1981 scores show a slight increase, but achievement levels remain significantly below the levels achieved before the beginning of the declining period.

- California Assessment Program (CAP) also reports that 1980 test results, when compared to 1970 national norms, place California's median twelfth grade students nine percentile points below the norm in reading, sixteen percentile points below in written expressions and seven percentile points below in mathematics.

- National Institute of Education reports a significant decline in science achievement scores from 1969-1977 for seventeen-year-old students.

Academic Course Enrollments and Implications

- College Entrance Examination Board (CEEB) reports that fewer California high school students enroll in advanced courses in English, Mathematics, Social Studies, Biological Science, and Physical Science than do students nationally.

- American Association for the Advancement of Science reports that students who take no math or science after the tenth grade have "effectively eliminated" science and engineering as careers. These preparatory courses are simply not offered at the college and university level, so entire fields become closed to students . . . .

Impact of Elementary School Experiences

- The California Elementary School curriculum has emphasized basic skill instruction during the last decade. Increased instructional time and other resources have been devoted to this effort.

- The American Association for the Advancement of Science reports that less time is devoted to science instruction in the elementary school than to any other subject.

- The National Council for the Social Studies reported that in California, 70 percent of K-4 teachers indicated they were teaching little or no social studies due to increased emphasis on basic skills.

Rigor of Curriculum Content

- University of California reports that the majority of entering students have taken four years of high school math and their mean SAT scores and G.P.A.'s are well above the state and national averages of students entering college. Nonetheless, numbers of students encounter difficulties with college math because the content of their high school classes was not fully equivalent to the college preparatory level. In many high schools a two-year algebra sequence starts with pre-algebra concepts and does not include advanced algebra concepts.

- CEEB reports that smaller percentages of California students report their academic credits were earned in accelerated or honors courses. The difference is most notable in the sciences.

- CEEB also reports that in all areas except mathematics, California students report having received higher grades than the average student nationally. Yet on measures of achievement, California students demonstrate less mastery of the content.

Academic Standards

- California State Department of Education reports that the "typical" school district requires its graduates to have three years of English, one year of American history, one semester of American government, one year of math, and one year of science.
- In California, school districts establish their own graduation requirements and usually allow individual high schools or teachers to design their own curricula. Thus, there is often little comparability between course content in the same subject among high schools within a district or among class sections within a high school.
- National Council for the Social Studies reported in The Status of Social Studies in the Public Schools of the United States that 80% of California high school social science teachers were free to teach whatever they wanted.

In response to declining achievement, the faculty senates of the California Community Colleges, the California State University, and the University of California have released a joint document for review and comment by interested persons on required competencies in writing, reading, and mathematics for students to perform successfully in college courses, and plan to issue a future statement on competence in science. The two senior segments have tightened their admission standards regarding high school subjects for implementation in 1984 by the State University and in 1986 by the University. In addition, a committee of University faculty has asked the State's 3,500 schools with eighth grades to distribute a letter, printed in both English and Spanish, to the parents of their 350,000 eighth-grade students urging them to become actively involved in improving the academic preparation of their children. (The full text of the letter was printed in the October 1981 issue of California Notes, published by the University of California.)

While these actions cannot be faulted, the new University and State University requirements in English and mathematics will pose problems for secondary schools understaffed to meet these demands or to teach science courses that have sufficient rigor to meet the expected competency standards.

Three critical issues are evident from conditions in elementary and secondary school science and mathematics programs: (1) a significant number of teaching positions in mathematics and physical sciences are unfilled, (2) support systems for the needed teachers have eroded, and (3) science facilities and equipment are becoming seriously inadequate.

WEAKNESSES OF SCIENCE AND MATHEMATICS TEACHING IN ELEMENTARY AND SECONDARY SCHOOLS

California's problems at the elementary and secondary school level are part of a national picture of inadequately prepared teachers, insufficient support, and outmoded resources. In recent testimony to the Senate Labor and Human Resources Committee, Lewis M. Branscomb, chairman of the National Science Board, reported that only one-third of the nation's students take mathematics beyond the tenth grade and that one-third of the nation's high schools do not offer enough mathematics courses to qualify their graduates to enter engineering colleges. As a result, one-third of the students entering engineering colleges have to take remedial math courses. He warned that the shortage of qualified mathematics and science teachers in high schools is jeopardizing the future availability of qualified scientists, engineers, and technicians: "Over 90 percent of the states now report shortages of mathematics teachers at the secondary level, and roughly a third of the secondary school science teachers did not themselves major in science." Although all high school students in Japan, the Soviet Union, and Germany take four years of mathematics, he reported while only 6 percent of American students do so. "Over a period of time," he stated, "this difference will surely tell in industrial production, perhaps even in our defense posture. It will surely tell in the quality of preparation given our young people for living in a highly technological world." At the same hearing, John B. Slaughter, director of the National Science Foundation, said that the Foundation would shortly establish an 18-member Commission on Pre-College Education in Mathematics, Science, and Technology: but F. James Rutherford, chief education officer for the American Association for the Advancement of Science, told the Committee that further study by that commission or any other was unnecessary: "the rapid decline of science and math education is undermining the nation's economic health, productivity and national security. We have already identified the problems in science and engineering and do not need to spend another two or three years trying to figure out what is wrong. As a nation we need to get on with the job right now of strengthening our science education enterprise" (The Sacramento Union, April 16, 1982).

Testifying before the Subcommittee on Science, Research and Technology of the House of Representatives, Sarah E. Klein, president of the National Science Teachers Association--the largest science education organization in the world--noted that although science education accounted for approximately one-half of the National Science Foundation's budget in 1959, its share had been slashed to a low of 7.5 percent by 1980 and would be eliminated entirely in 1983-84 except for $700,000 to support the aforementioned Commission on Science and Engineering Education. She pointed out that $3 million had been spent on such studies over the past five years and that the crisis in secondary school science and mathematics education resulting from the critical shortage of qualified science and mathematics teachers is already well demonstrated. She presented data for 1980 and 1981 which indicated that the shortages are becoming even more severe (Table 10). Her data indicated that of all newly employed science and mathematics teachers in 1981, 50.2 percent were unqualified to teach science or mathematics because of lack of specific training in these fields and were employed on an "emergency" basis because no adequately prepared teachers were available.

TABLE 10

SUPPLY OF HIGH SCHOOL TEACHERS IN SELECTED SUBJECTS
BY NUMBER OF STATES REPORTING SHORTAGES AND SURPLUSES
IN 1980 AND 1981

Subject	Critical Shortage 1980	Critical Shortage 1981	Shortage 1980	Shortage 1981	Adequate Supply 1980	Adequate Supply 1981	Surplus 1980	Surplus 1981
Physics	21	27	22	15	3	4	2	1
Mathematics	16	18	19	25	7	2	4	1
Chemistry	10	9	25	29	9	6	5	2

Source: Klein, 1982, p. 3.

Separated into census regions, her data show that the Pacific states, including California, whose high-technology industries require well-trained personnel in science and mathematics are in the worst condition:

Region	Percentage of Newly Employed Science and Mathematics Teachers Who Were Unqualified Because of Inadequate Preparation in These Disciplines
Pacific States	84%
Mountain States	23
West North Central States	43
West South Central States	63
East North Central States	46
East South Central States	40
North East States	9
Atlantic States	43
South Atlantic States	50

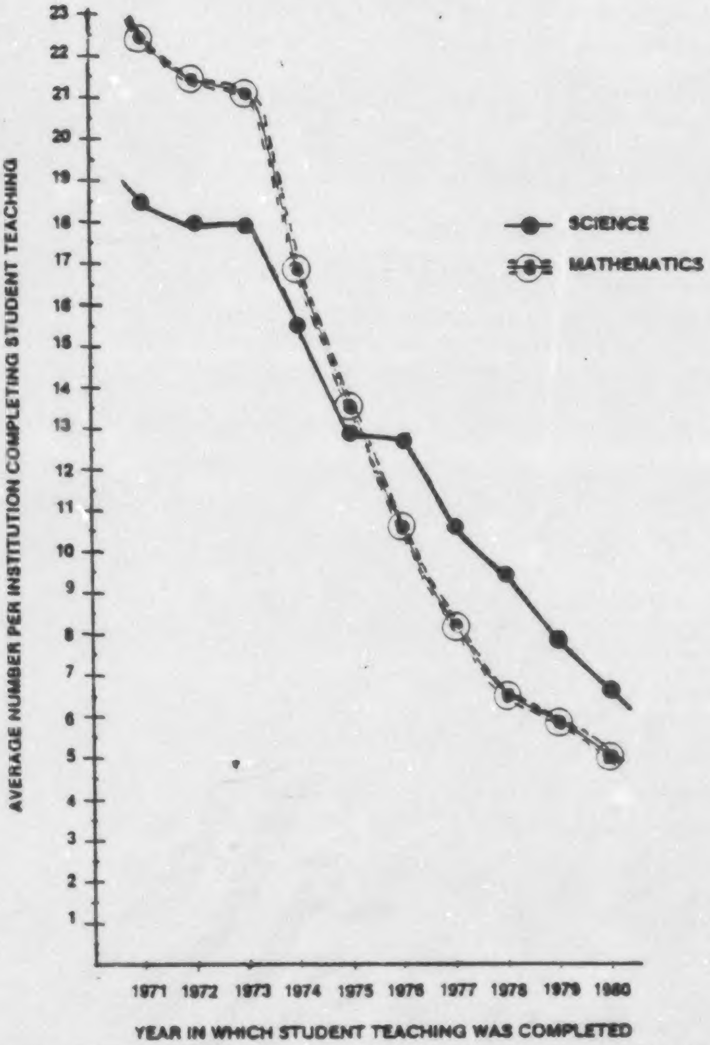
Source: Klein, 1982, p. 4.

Mrs. Klein also reported that five times more science and mathematics teachers left teaching last year for employment in industry than retired, and that 51 percent of elementary school teachers report that their undergraduate training did not give them any preparation to teach science. Perhaps the most startling data of her testimony concerned the declining numbers of students who are preparing to teach high school mathematics or science. Over the 1970s, the number of students prepared to teach science dropped from an annual average of 18 to 7 per teacher-training institution, while those prepared as mathematics teachers plummeted from 22 to 5 (Figure 24). Mrs. Klein contended that America is moving toward the point where reduced quality of science and mathematics education in elementary and secondary schools dangerously threatens "national security and the nation's efforts toward improved productivity" (p. 3).

Other data point to a similar conclusion. A national survey reported that nearly 10 percent of the mathematics teaching positions in the secondary schools in the U.S. were vacant as of 1977-78 (National Council of Teachers of Mathematics, 1981). More recently, in 1980 the membership of the Association of High School Science Teachers suffered a loss of 10 percent, and most of the 1,000 teachers who left were hired by industry (Bromley, 1981, p. 159). And Chapter Five of the report by the National Science Foundation and the Department of Education on Science and Engineering Education for the 1980s and Beyond (1980) concludes that the public schools

FIGURE 24

AVERAGE NUMBERS OF SECONDARY SCHOOL SCIENCE AND MATHEMATICS TEACHERS PRODUCED IN TEACHER TRAINING PROGRAMS AT U.S. COLLEGES AND UNIVERSITIES



Source: Klein, 1981, p. 14, summarizing data from 108 teacher placement offices participating in National Science Teachers Association Surveys.

are not adequately carrying out their science and mathematics education tasks. It notes that in comparison to other industrialized countries, in the United States, science is not defined as a "basic" skill or subject and mathematics is defined as mechanistic computational skill. When elementary school mathematics instruction began to concentrate on set theory during the late 1950s, children did not learn computation and problem solving. Since the late 1970s, concern about declining achievement and minimal skills has led to increased attention on basic skills, but just as schools are using reading textbooks that employ simplified vocabulary and sentence structure, they are using mathematics textbooks that concentrate on drill and computation at the expense of common applications. Just as tests have shown that children have mastered the basic techniques of reading but have trouble with comprehension and interpretation, similarly, children can do simple whole number computations but have trouble solving common problems (pp. 45-49).

A number of educational organizations, including the National Congress of Parents and Teachers, see dangers in the emerging emphasis on basic skills. The Congress has expressed its concern as follows:

> Though emphasis on acquiring basic skills is at the heart of the educational process, there is a distinct possibility of basics becoming the curriculum rather than just part of the curriculum. Another problem, with an overemphasis on basics, is a tendency to teach children only those things for which they will be tested, a tendency that leads to mediocrity (What are the Needs in Precollege Science . . ., 1980, pp. 252-254).

Because science is not viewed as "basic" by the general population or educators, what little emphasis has been devoted to science is diminishing.

WEAKNESSES IN CALIFORNIA

Whatever problems exist at the national level relative to science and mathematics in the public schools are compounded in California. California ranks well below the national average in the number of secondary school science and mathematics teachers produced by teacher training programs.

Many California school officials say they do not have (and cannot obtain) enough qualified mathematics teachers to give every high school student the two years of mathematics set by the California

State University as its new minimum admissions requirement. Tom Shaw, a placement officer at California State University, Long Beach, told David Savage, education writer for The Los Angeles Times: "In the last four years, we've averaged less than seven candidates a year who are credentialed to teach math. And we get about 400 requests a year for math teachers. We're also not producing any physics or chemistry teachers" (Savage, 1982). San Jose State University has graduated only nine students certified to teach secondary school physical science in the past five years (Castillo, 1981). And in the Times, Savage reports that the five-year shortage of mathematics teachers in the Los Angeles school system is getting worse. Its Teacher Selection Office surveyed 10 area colleges and universities who train prospective teachers and found only 15 possible candidates among all 10 for mathematics positions. In 1981-82, as a result, the district had to issue 273 "emergency contracts" for mathematics teachers who were less than fully qualified to avoid canceling mathematics classes, and it is launching a nationwide recruiting campaign, concentrating on New York City, Boston, Chicago, Detroit and a few other large snow-belt cities, and offering the Southern California climate and $13,000 to $15,000 a year in salary for teachers in shortage areas because so few are available in California.

According to an informal poll at two meetings of the Mathematics Liaison Committee of the Articulation Council, approximately 26 percent of the junior high school mathematics teachers in one of the State's largest school districts were not certified in mathematics; representatives of seven colleges and universities indicated that the total number of mathematics credentials they are issuing this year is 16--averaging out to slightly over two per institution; and community college representatives reported experiencing increased difficulties hiring qualified mathematics instructors and consequently are using an increasing number of "limited service" credentials, raising the possibility that minimally qualified instructors will be unable to teach college-level mathematics adequately. College graduates can often earn twice as much in industry as they would in teaching, but Viggo Hansen, professor of mathematics education at California State University, Northridge, believes that salaries are not the only attraction of industry: "The whole image of public education is so bad," he says, "that no one wants to go into the field."

California's shortage of qualified teachers is not limited to mathematics or science, of course. Severe shortages exist in vocational and technical education, bilingual education, and special education for the handicapped. And California's problems of student achievement do not stem merely from teacher shortages. In some California school districts, students are spending the equivalent of only 10 1/2 years compared to 12 years elsewhere because their school year and school day are shorter than elsewhere ("Statewide High School Standards Urged," 1982). But adequately prepared high school mathematics and science teachers are imperative to upgrade the skills of potential engineering and computer science students as well as many others in other fields. (The Commission plans to discuss this issue at greater length in its forthcoming report on remediation in California public postsecondary education.)

Cities in other states have confronted the problem of attracting and retaining mathematics and science teachers in ways prohibited in California. For example, during each of the last two years, and despite initial opposition of teacher organizations, Houston has paid an $800 bonus to teachers in shortage areas--mathematics, science, and bilingual and special education. This year, it will increase the bonus to $2,000. Leslie Miller, assistant to the Houston school superintendent, maintains, "this is just a matter of supply and demand. We increased the salaries in the areas where there's a scarcity." Miller has found that the first two years of the bonus-pay experiment has resulted in a substantial decline in the turnover rate (Savage, 1982). In California, however, State law and court rulings forbid a "differentiated" salary structure, whereby some teachers would be paid more than others with the same experience and education. At least several superintendents of California school districts believe that this law must be changed. Teaching salary levels have been and will continue to be stagnated, yet California's technological economy requires a work force particularly well trained in mathematics and science.

CONCLUSION

Certainly no simple and immediate solution is possible for the problems of student numbers and preparation cited in this chapter. For years we have known that the 18-to-24-year-old age group would decline by about 15 percent during the 1980s. We have also known that the traditional engineer is a white male. Thus although ethnic minorities make up over 22 percent of the U.S. population, they account for only 4 percent of all scientists and engineers; and although half of the nation's workers are female, only 9 percent of scientists and engineers are women. Boys and girls score equally well on standardized mathematics tests until the sixth grade, but then the female test scores begin to drop and reach only 51 percent of the male test scores by the twelfth grade. In the absence of compelling evidence to the contrary, this decline must be regarded as environmental. Not only is more emphasis needed on elementary and secondary school science and mathematics, but more realistic career information and greater encouragement of women and minorities to enter technological and scientific careers are essential if the eligibility pool of engineers and computer scientists is to be expanded, let alone maintained at its present level.

Women now constitute more than one-half of all college students, but in 1981 women constituted only 10.0 percent of all bachelor's degree recipients in engineering nationally and only 9.4 percent of those in California. Presently, Blacks receive approximately 2 percent of the nation's bachelor's degrees in engineering, as do Hispanics, and their percentage in California is not greatly different. If California and other sunbelt states with large minority populations cannot bring their minority populations and women into the mainstream of technological careers, they will not be able to sustain their high-technology economies.

Nancy Kreinberg, director of Mathematics and Science Education for Women at the Lawrence Hall of Science, believes that the greatest need for mathematics literacy exists among today's girls and young women; yet her findings and recommendations apply as well to minorities. She comments that "women still comprise the largest pool of underutilized workers that can supply scientific and technical personnel to meet present and future demands," and she recommends that California should take the lead in requiring all students to take more mathematics, in interesting more girls and young women in mathematics, in establishing new teacher education programs in mathematics, and in offering continuing education classes in mathematics for adults (1981).

Many colleges and universities have developed "math anxiety" courses for women and minorities that tend to improve their Graduate Record Examination scores, but such remedial action at the college level is too late to encourage students to embark on the calculus sequence that is part of an engineering, science, or mathematics curriculum. To expand the pool of women and minority students in the future will require an overhaul of teacher education and elementary and secondary school mathematics and science programs. While it may take at least a decade to accomplish the necessary changes, it is imperative that California quickly increase its efforts in this direction.

Colleges and universities need to encourage more students to prepare for careers as mathematics and science teachers, and they should examine closely whether present certification requirements for teachers are adequate to overcome the issue of mathematics and science illiteracy among students in the elementary and secondary schools. High school counselors should become more aware of the opportunities for employment in education as science and mathematics teachers. Of course, none of these actions will be of social benefit if salaries for teachers in these disciplines are not increased substantially.

CHAPTER SIX

INDUSTRY AND GOVERNMENT INCENTIVES FOR TECHNOLOGICAL EDUCATION

Part of America's technological problems stem from its flagging commitment to basic research and to the research-and-development process. Between 1964 and 1980, as a proportion of the Gross National Product, federal expenditures for research and development fell by 43 percent; and between 1965 and 1977, total national R&D expenditures dropped by 24 percent, rising by only 1 percent between 1978 and 1980. In 1978, American business and industry spent nearly $33.6 billion on research and development--but gave only an estimated $85 million to universities for research. This corporate support represented only 3 percent of higher education's total research expenditures that year, and a decrease from its 5.5 percent level in 1960 (Boyer and Hechinger, 1981, pp. 36-37). Declines in federal support for research have led universities to turn increasingly to the private sector and to state government for research support. At a time when universities lack adequate numbers of faculty to meet the increase in engineering and computer science students, they have lacked research support to encourage bright Ph.D.s to join the faculty.

NEW INDUSTRIAL INCENTIVES

Recently, industry and industry-related foundations have launched a variety of efforts to aid universities in meeting their teaching and research goals in high-technology areas that deserve citation here as actions illustrating the benefits of industry-university ties:

- In September 1981 the Exxon Education Foundation announced a $15 million grant program to 66 engineering schools which will award 100 $50,000 three-year Exxon Teaching Fellowships in graduate engineering programs leading to the Ph.D. and teaching careers. Each Fellow will receive a stipend of $12,000 for the 1982-83 academic year, $13,500 for the second year, and $15,000 for the third year, plus tuition and fees. The program will also include 100 faculty assistance grants of $20,000 each year for five years to selected engineering departments to be used as supplements for junior non-tenured faculty. The California institutions sharing in the program are: California's Institute of Technology, Stanford, the University of California at Berkeley and at Los Angeles, and the University of Southern California.

- In November, the same foundation announced a total of $1.8 million in faculty development grants to six engineering schools at traditionally Black institutions, each of which will receive $100,000 per year for three years. Robert Payton, president of the Foundation said, "We're giving this type of support because we believe faculty development is the most important element in these colleges at this time." The Foundation has left it up to each of the six schools to determine how to use the grant funds, with the deans of engineering considering several options including salary supplements, increasing the number of teaching assistants, faculty travel, added research support, and forgivable loans to students who decide to enter engineering education. (Engineering Education News, 1982a, p. 4).

- The Atlantic Richfield Foundation has announced a $5 million four-year program of support for doctoral students and junior faculty in selected science and engineering departments at 30 universities. Its purpose is to "alleviate a serious national problem by making academic careers in science and engineering more attractive" (Engineering Education News, 1982b, p. 1). The Foundation is in the process of selecting the institutions and departments that will receive these grant funds.

- The Board of Directors of the American Electronics Association has approved the establishment of an industry-wide standard of 2 percent of a company's R&D expenditures for support of education, either directly by the company or through an AEA-created foundation. This action is expected to produce between $30 million to $50 million per year for engineering schools.

- The Semiconductor Industry Association is designing a program whereby semiconductor companies will join together to strengthen engineering education and faculty research expertise. It aims at large umbrella grants rather than funding of small projects. The program will begin with $4 to $5 million, increasing to $10 to $20 million in a few years.

- American Telephone and Telegraph has loaned John W. Geils to the American Association of Engineering Societies and the American Society for Engineering Education to head up a two-year project to counter increasing engineering faculty shortages and disincentives. His study is supported by DuPont, Exxon, General Electric, General Motors, General Telephone and Electric, IBM, and Union Carbide, as well as AT&T.

- Dow Chemical has more than doubled its aid-to-education funding in 1982 because of engineering education's problems, increasing its contribution to $4.4 million this year.

- San Francisco's Bechtel Group is now financing scholarships totaling nearly $300,000 annually.

- Eastman Kodak has launched a $200,000-a-year program of "Teaching Incentive Grants" to supplement faculty salaries mainly in chemical engineering.

- Du Pont, which last year made 22 "Young Faculty Grant" awards at $22,000 each in engineering and chemistry, this year is making 27 grants at $27,000 each.

- Sun Company is donating nearly $300,000 over a five-year period to three engineering departments at the University of Texas at Austin and several other universities for salary supplements or awards to professors and as assistance to students who are seeking advanced degrees for teaching careers.

- General Electric, General Motors, and Boeing have joined together to launch a new productivity center at Rensselaer Polytechnic Institute in Troy, New York, with financial commitments of $1 million.

- Control Data Corporation is developing at Purdue University in Indiana a center for research in computer-aided design and manufacturing and has made a multi-year commitment to permit its systematic development.

- Digital Equipment Company has developed a close working relation with Carnegie-Mellon University in Ohio directed toward the use of small computers, which employs the Company's facilities and the University's faculty and graduate student capabilities.

- Six companies are each providing annual grants of $100,000 to the Silicon Structures Project of the California Institute of Technology, which is directed toward the development of design software for very large-scale integrated circuits. In addition, an engineer from each company is assigned to Caltech for a year.

- MIT's Center for Polymer Process Research, initiated partially through support from the National Science Foundation, has proven so valuable that industrial sponsors now completely support its work.

- Hewlett-Packard, which gave $7 million in education grants last year and which largely paid for Stanford University's School of Engineering building, recently joined with 16 other electronic firms to establish a Center for Integrated Systems at Stanford University. Each company has committed to pay $750,000 each toward the center.

- Applied Technology and other companies are working with Mission College in Santa Clara to train and upgrade their assembly line workers.

- And Intel Corporation is working with faculty members of the University of California at Berkeley who had developed a prototype of a new electronic technique involving switched capacitors, in order to further the technique and bring the idea to successful commercial realization.

FEDERAL INCENTIVES

At this time, no federal program of incentives can be clearly identified.

According to George Millburn, Deputy Under Secretary of Defense for Research and Advanced Technology, the Department of Defense is considering the establishment of a program whereby each of the armed services would provide 100 $25,000 three-year awards to students in the form of loans, with the loans forgiven if the students work for the government for a given number of years, but the program has not been presented to Congress. Meanwhile, officials at the National Science Foundation are meeting with representatives of other federal agencies to develop a Federal Agency Fellowship program which could conceivably be a part of their agency budgets in 1983-84. But according to Harry S. Havens, Assistant Controller General of the General Accounting Office, federal support for engineering education will decrease during the present year by 33 percent from fiscal 1980 levels, since 14 of the 39 programs that have supported engineering students are being dropped in order to reduce federal spending.

STATE INCENTIVES

Many states are taking the initiative to enhance the climate for high technology within their borders and to alleviate the shortage of engineers and engineering faculty and instructional equipment at their universities.

In California, Governor Brown last year proposed a Microelectronics Innovation and Computer Research Operations (MICRO) program to be established at the University of California. As proposed, the program would have included $2.6 million for capital outlay and equipment for Cory Hall on the Berkeley campus, plus $5 million for a matching grant program with business for basic research. The budget that passed the Legislature included the $2.6 million for Cory Hall but only $1 million for matching grants. In early 1982, work on Cory Hall was stopped when the Governor was forced to freeze all capital outlay projects because of a looming budget deficit; but subsequently the freeze was lifted and construction contracts were let. For 1982-83, the Governor has announced his "Investment in People" program which is designed to (1) provide additional and improved mathematics and science instruction in the high schools, (2) encourage employment-based training in the Community Colleges, (3) expand pilot employment preparation projects among Aid to Families with Dependent Children applicants, (4) increase research and education in the areas of engineering, computer sciences, and related basic sciences in the University, and (5) promote education in engineering, computer sciences, and related fields through faculty development and instructional equipment grants in the State University. The last two items would be allotted $4 million and $3 million, respectively. Although the amounts proposed are small, the program represents an important initiative to improve high-technology education in California.

Elsewhere in the West, the Western Interstate Commission for Higher Education (WICHE) reports (1981, p. 12):

- The University of Wyoming is undertaking an $18 million expansion of its engineering facilities and is increasing faculty salaries to make them relatively competitive with other states.

- The New Mexico legislature has funded a new engineering building at New Mexico State University and authorized a five-year $5 million-per-year science and engineering equipment improvement program for all the state's universities, on recommendation of the Governor's Committee on Technical Excellence, chaired by the president of the Sandia Corporation.

- Arizona State University has embarked on a five-year $32 million program to create a "center of excellence" in electronic and computer fields by expanding facilities, adding equipment, and increasing faculty by 63 percent. Local industry has been the prime mover in developing the plan and committing substantial private financial support, thereby securing the endorsement of the governor, the legislature, and university administration.

- In Colorado, Governor Lamm is urging legislators to increase state support for research at state universities, saying Colorado has the opportunity "to become a technological cousin of California's Silicon Valley, and it is an opportunity we would be foolish to pass up." He has stated, "To insure our positive competitive position, we are going to have to place new reliance and responsibility on higher education."

- WICHE itself has launched an 18-month study of "State, Higher Education, and Industrial Cooperation to Expand High Technology Human Resources in the West" with three primary objectives:

  - To develop sound data . . . on the supply of and demand for high technology and energy-related manpower in the West;

  - With such data as background, to identify a range of solutions to the problems; and

  - To contribute to regional and state initiatives to address them (Sirotkin, 1982, p. 1).

  The first six months of the study are being funded out of $64,000 of WICHE resources while the remaining 12 months will require an additional $185,000.

Elsewhere in the nation, other governors are also taking action ("Falling State Revenues . . .," 1982, p. 15):

- In Illinois, Governor Thompson's high-technology task force has recommended locating and funding high-tech research centers in Illinois. "It is time we moved ahead at full throttle to compete with the strength of Silicon Valley in California and microchip corridors in Massachusetts, North Carolina, and Texas," he has said, "and we're doing just that." Last August, the state launched a million-dollar advertising campaign to sell itself as a location for industry, tourism, and high-technology investment.

- In Kansas, Governor Carlin has proposed a severance tax on oil, gas, and coal produced in the state to raise an estimated $124 million a year and thereby increase faculty salaries by 8.75 percent in order to meet competition from other states and private industry for faculty members in certain professional and technical fields.

- In Mississippi, Governor Winter has told state legislators, "If you are disgusted with seeing us continue to lose blue-chip industries to Georgia and South Carolina and other states because those states are perceived to have better technical training programs, I urge you to do something about it. He has proposed the creation of a permanent endowment for specific educational and economic-development needs supported by increasing the 6 percent oil and gas severance tax to 9 percent, which would produce about $68 million a year.

- In Missouri, Governor Bond has proposed that public funds be provided for "challenge grants, which state colleges and universities can use to match private-sector funds to pursue research and applied projects leading to the creation of high-technology jobs for decades to come."

- In New York, Governor Carey has told the legislature that New York should use its higher education system to full advantage: "We must involve these institutions in implementing our strategy for economic development, forming a partnership with the business community to provide the research, instructional, and technological-development capacity that industry increasingly needs," he said.

- In South Carolina, Governor Riley has proposed a "South Carolina Research Institute" to link higher education to industrial development.

These examples of state initiatives aimed at shifting their economy toward high technology seek to emulate the success of existing university contributions to community and regional economic development, including Stanford's cooperation with industry in the "Silicon Valley" of San Mateo and Santa Clara Counties, the ties of Eastern Michigan University and the University of Michigan to industry along the "Plymouth Road Corridor" between Ann Arbor and Detroit, and the participation of Duke University, North Carolina State University, and the University of North Carolina-Chapel Hill in the Research Triangle Development of North Carolina. The Research Triangle enterprise represents the clearest success of a state-induced vehicle for coordination, stemming from a $24.4 million allocation from the North Carolina General Assembly for the construction of a micro-electronics center in the Research Triangle Park. Early observers of the effort thought the combination of government, business, and academia might fail, but employment directly related to the Research Triangle now exceeds 10,000 with an annual payroll of $200 million. New industrial investment in North Carolina has averaged $2 million per year for the past five years; North Carolina's unemployment rate is about 2 percent below the national level; and the state has gained a reputation for industrial leadership and innovation throughout the nation.

CONCLUSION

These examples demonstrate that industry and state governments are providing important incentives to engineering education, while the federal government is rapidly reducing its participation. Competition among states to attract and maintain high technology industries within their border is becoming intense, and Governor Brown's "Investment in People" initiative represents one effort to meet California's needs through improved education and training.

Industry is making major efforts to support engineering education, but a major part of their support remains concentrated in only a few "pacesetting" research universities--about one-fourth of the engineering schools accredited by the Accreditation Board for Engineering and Technology. This has led T. A. Murphy, Vice President of Engineering at Fluor Engineers and Constructors, Inc., and chairman of the Engineering Advisory Council at California State University, Long Beach, to note that such grants as those from the Exxon Education and Atlantic Richfield Foundations to supplement faculty salaries in selected institutions result in making faculty recruitment more difficult for other good institutions, such as Long Beach. In a letter to the Engineering Advisory Council at Long Beach, he called attention to the fact that CSU Long Beach is a key supplier of technical talent to industry in the Los Angeles and Orange County areas and urged that funds be provided to it for salary supplements in order that it can continue to provide the engineering talent necessary to the area. Yet unless the Legislature appropriates special funds on a permanent basis for such salary supplements, it is doubtful if a workable solution can be found.

The California State University is more restricted than most institutions of higher education in administering faculty salaries flexibly to accommodate fluctuations in the marketplace and special problems of particular departments and campuses; and its requires salary schedule flexibility by the Legislature and the Governor if its needs for faculty are to be met. State funds will be necessary to continue its salary differential experiment beyond the 1982-83 year. In addition, the University of California cannot be expected to use its own funds continuously for these salary supplements.

CHAPTER SEVEN

IMPLICATIONS FOR STATE AND INSTITUTIONAL POLICY MAKERS

This past April, some 50 government officials, university presidents, and corporate executives held a National Engineering Action Conference conceived by Paul Gray, president of MIT, and chaired by E. E. David, Jr., president of Exxon Research and Engineering. With the theme, "the time for action to deal with the precarious state of engineering education has come," the Conference participants concluded that if present trends continue, with more than 1,600 engineering faculty positions already vacant and outmoded campus engineering laboratories deteriorating, young men and women will not receive the engineering education they deserve and that America's economy and society urgently require. They issued a "call to action" including this agenda:

For higher education:

- Set engineering faculty compensation at a level competitive with the market;
- Increase graduate student stipends to encourage a larger number of U.S. residents to become doctoral students;
- Give highest priority to modernizing instructional and research equipment;
- Reconsider the Ph.D. requirement and place greater reliance on practical skill and knowledge in filling faculty positions;
- Consider establishing semi-autonomous colleges of engineering, such as exist in other professional disciplines; and
- Improve research and instructional productivity by providing optimum technical assistance.

For academic and professional societies:

- Expand scholarship and fellowship aid to engineering doctoral students using related educational foundations, and make direct grants to the schools;

- Establish programs to aid the exchange of engineers between industry and academe; and
- Monitor the manpower supply and demand model in order to help identify actions that will maintain an adequately prepared supply of graduates and faculty.

For industry:

- Provide direct financial support to U.S. resident master's and doctoral candidates in the form of traineeships, scholarships, and awards;
- Assist engineering departments in modernizing their equipment and instrumentation, through financial grants, donation of new surplus equipment, and innovative debt financing;
- Create opportunities for junior faculty to increase their income through consulting, summer employment, tutorials and grants;
- Encourage and provide incentives for qualified employees to teach in engineering as part-time, loaned or full-time faculty members; and
- Actively pursue opportunities for purchasing research from universities instead of conducting it in-house.

For government:

- Support programs for providing fellowships, summer internships, traineeships, and other aid to doctoral candidates through NSF and other mission agencies;
- Place high priority on helping educational institutions modernize equipment and facilities in engineering laboratories;
- Enlarge support for university government cooperative research; and
- Support studies and hearings to determine the nature and national scope of the engineering faculty shortage. ("National Engineering Action Conference," 1982; see also David, 1982.)

Each of the previous six chapters have highlighted several of these concerns about engineering and computer science education. This concluding chapter develops the implications of these issues for legislative and university policy making in California.

PROGRAMS AND ENROLLMENTS

California faces a continuing high demand for engineers and computer scientists into the late 1980s and a particularly high demand in the immediate future for Ph.D. graduates in these fields. Undergraduate enrollments in these programs in California's universities have increased to help meet this demand, but cannot be further expanded without sacrificing quality. Graduate enrollments have changed little over the past five years. Support for these programs should be increased to assure continued excellence and to permit cautious expansion in the future to meet the State's technological needs. Unlike many other states, California reaps direct rewards from its investment in these programs: up to 90 percent of their graduates find employment or return to jobs in California rather than move out of state.

Enrollments in these programs will continue to fluctuate periodically, as they have in the past, with little relation to the job market except as prospective students hesitate to enroll because of reports in the mass media about the lack of jobs, leading four or five years later to an undersupply of graduates. But state and institutional policy makers should not be disuaded by periodic reports of an oversupply of engineers or computer scientists from maintaining continued long-term support for these programs.

PLACEMENT OF NEW PROGRAMS

The major task for program planners at the University of California and the California State University is to agree on the placement and distribution of centers for research and instruction in specialized technologies such as robotics, computer-aided design and computer-assisted manufacturing (CAD/CAM), microelectronics, and very large scale integration (VLSI). These programs should not be offered on every campus, even though most campuses will need to offer at least introductory courses in them, and the State should not support large-scale programs on all campuses. The segments themselves in cooperation with the Commission should determine where these specialized centers of excellence should be located, taking into account faculty expertise, campus location, joint segmental use, and space availability as factors in these determinations. For example, only three or four robotics centers currently exist on university campuses in the United States. One or two should be established on California campuses.

At the same time, academic planners in each segment and the Commission need to clarify the engineering specialties or majors offered by the California State University, Northridge, and the University of California at Los Angeles, and the engineering technology specialties offered at California State Polytechnic University, Pomona. Northridge was initially authorized to offer only four majors, but it now has four departmental combinations and its catalog lists 15 different majors. UCLA claims that it cannot separate its undergraduate enrollment into majors. Yet students at UCLA, as at Northridge, are advised that all sequences of advanced level courses must be approved by an advisor before enrolling in the courses, thereby essentially separating students by majors. Both systemwide offices and the Commission need clarification of the offerings on these campuses and at Pomona.

ENCOURAGING GRADUATE ENROLLMENT

As noted on pp. 87-88 above, the participants in the National Engineering Action Conference agreed that the urgent task of attracting the best domestic students into graduate programs in engineering deserves the attention of higher education, academic and professional societies, industry, and government.

To attract sufficient numbers of such students, more fellowships and assistantships with substantial stipends are needed. Albert Bowker, while serving as Assistant Secretary for Postsecondary Education in the Department of Education, sought more reasonable funding for graduate assistants. Although a fellowship program would not guarantee that doctoral students would go into teaching, he proposed a loan program like that used by the Public Health Service to recruit medical doctors, whereby annual loans would be forgivable for each year that a recipient later spent teaching in an engineering school or in another particular shortage area. "A lot of people would stay in graduate school if they could move up from real poverty to genteel poverty," he stated (National Academy of Engineering, 1981, p. 52). Many other educators as well as industrial and governmental leaders hold to this view.

Some states have taken action to increase annual stipends available to graduate students, but in California they continue to be funded in the range from $3,400 to $8,000. The Board of Directors of the Institute of Electrical and Electronic Engineers has recommended that graduate stipends be increased to 50 percent of the starting salaries of baccalaureate engineering graduates ("Quality is Main Problem in Engineering Crisis," 1982, p. 32), and both institutional and State policy makers should consider its recommendation.

REVIEWING THE COSTS AND BENEFITS OF INTERNATIONAL ENROLLMENTS

The presence of foreign students in American colleges and universities contributes to the general welfare of the entire student population, the faculty, the institution, and the nation as a whole. The United States' commitment to providing educational opportunities to foreign students is virtually unequalled among the nations of the world and has become an accepted part of its extended-term foreign policy. This policy, coupled with the historical excellence of American postsecondary educational institutions, has led to high enrollments of foreign students in American colleges and universities, particularly in high technology programs such as engineering and computer science.

Currently, the greatest number of foreign students in the United States come in descending order from Iran, Taiwan, Nigeria, Canada, Japan, Venezuela, Saudi Arabia, Hong Kong, India, and Lebanon. In 1980-81, 311,822 non-resident aliens were enrolled in American colleges and universities--25 percent of them in engineering programs and another 17 percent in business administration. Their numbers increased by 9 percent last year; by the mid-1980s, some 500,000 are expected to be enrolled; and by 1990 one million may be enrolled (American Council on Education, 1982, p. 8).

The number of graduate degrees awarded to foreign nationals in engineering nearly doubled over the past decade. According to the Engineering Manpower Commission, in 1981 foreign students received 8.9 percent of the nation's engineering bachelor's degrees, 26.1 percent of its master's degrees in engineering, and 37.1 percent of its engineering doctorates (Doigan, 1982, p. 709). That same year at the California State University, non-resident aliens earned 20.1 percent of the engineering baccalaureates and 44.2 percent of the engineering master's degrees. At the University of California, they earned 8.9 percent of the engineering baccalaureates, 32.1 percent of the engineering master's degrees, and 32.6 percent of the engineering doctorates. At California's independent institutions, they earned 25.1, 34.0, and 37.9 percent of these degrees, respectively.

In computer sciences, non-resident aliens received 10.1 percent of the 1981 bachelor's degrees and 31.3 percent of the master's degrees in the State University, while at the University the figures were 4.3 percent of the baccalaureates, 24.8 percent of the master's degrees, and 35.0 percent of the computer science doctorates.

While foreign students provide substantial benefits to the American educational enterprise, their presence is not without its expenses:

- First, the high demand for technical education on the part of foreign students serves to impede, delay, or, in some cases, deny access to these programs to American students. While this competition presents a vexing problem for the nation as a whole, it is particularly acute in California. As indicated on pp. 40-41, six of the thirteen engineering programs in the State University, and all eight of those in the University of California, have been officially declared "impacted" at the undergraduate level, as have several engineering specialties at the master's and doctoral levels on some University campuses. As such, access to them is restricted and, as noted on page 42, higher admission standards are generally used as the final discriminant among applicants. Some campuses with impacted programs have designed their admission eligibility standards to give preference to American students (and, usually, to resident aliens), but opinions differ about the defensibility of such actions, and, as a result, most of the programs do not differentiate between foreign and American applicants.

  The joint effect of program impaction and the hesitancy of these institutions to deny access to foreign students can lead to situations where Californians are precluded from enrolling in an engineering program while foreign students are accepted. Even rare instances present difficult public relations problems to all institutions, but particularly publicly supported ones.

- A second problem presented by large enrollments of foreign students in engineering and computer science programs involves the costs of quality instruction in high technology fields. The per-student cost of instruction in engineering and computer science programs is generally not well documented at the national level and is not available in any form for California's colleges and universities, but there are indications that high technology programs rank above average in terms of expense. In California, non-resident tuition levels in the senior public segments are determined in large measure by the average cost of instruction for each of the two segments. Even taking into account the high level of these charges, the State does not get back from non-resident aliens enrolled in engineering what it expends on their education, particularly at the graduate level.

- A third problem attendant to foreign student enrollments in engineering and computer science concerns the transfer of technological information to foreign countries. This problem is particularly difficult because of the large number of foreign students enrolling at the graduate level. Robert McMaster of Ohio State University comments about the results of a preponderance of foreign students in graduate classes at his University: "we have transferred technology very effectively--they practice what we preach. Our industries did not practice what we preach so, in certain areas--shipbuilding, automobiles, and so on--we now are at a considerable national disadvantage" (National Academy of Engineering, 1981, p. 45).

  Russell R. O'Neill of UCLA has commented on the good and improving relationships that have been developed between UCLA and industry, leading to joint research, summer jobs for students, consultancies for faculty, and fellowships, but he warns that "obstacles still remain; for example, industry is reluctant to sponsor research that is likely to benefit foreign competition via the many foreign students studying engineering in the United States" (ibid., p. 43). And Donald Fink, director emeritus of the Institute of Electrical and Electronic Engineers, says that "we are educating our competition. I see no problem in educating non-Americans as such, but until we learn to compete in the international market--certainly an area that needs some new ideas--the problem is going to get worse" (ibid., p. 68).

  Two interests thus seem incompatible: Universities want funds from industry and government for graduate research, yet industry and government are reluctant to provide funds to educate their competition and thereby place the United States in danger of losing its world leadership position to other industrialized nations.

- Fourth and finally, at the same time that industry is reluctant to support foreign competition, some Congressmen, businessmen, and educators are concerned that too many foreign students find work in the United States rather than returning home. A 1980 survey indicates that about half of the foreign students on temporary visas have definite plans to work in the United States (National Science Foundation, 1982, p. 2). One of the major aims of opening educational opportunities in the United States to foreign students is to encourage them to return home and use their education to assist in the welfare and development of their own people; but large numbers of foreign students use American educational opportunities primarily as a means of gaining permanent residence in this country.

As part of a bill to reform U.S. immigration laws (S2222 in the United States Senate, and HR5872 in the House of Representatives), Congress is considering legislation that would require all foreign students to return to their homeland for two years after graduation from an American college or university before being allowed to apply to live and work permanently in the United States. Arnold Leibowitz, special council to the Senate Immigration Subcommittee, states that the proposal results from concerns among lawmakers that "we're building up an excessive dependence in high-tech fields on foreign students."

Some educators and industrialists oppose the legislation, claiming that it would lead to a critical shortage of faculty and professionals in engineering and other technical areas, but several professional associations support it because they contend that foreign engineers are willing to work at salaries below those paid to or demanded by American engineers, thereby placing their members at a disadvantage (Middleton, 1982).

Under present law, foreigners who hold professional degrees are automatically considered to be "aliens of exceptional ability." This category virtually assures Immigration and Naturalization Service approval of their requests for permanent-resident status and labor certificates--the number of which in engineering occupations more than doubled between 1976 and 1980.

The inability of educational institutions to compete in the marketplace for American students with engineering doctorates leads to the recruitment of many of these non-resident aliens as faculty. Russell Jones of the University of Massachusetts, Amherst, points out a resulting problem:

> In many engineering fields, foreign born Ph.D.'s are available in large numbers for faculty positions. These graduates typically have received their early engineering education outside the U.S. and have come here for graduate engineering education. While they often are among the brightest of the graduate students, they often lack practical experience relevant to U.S. engineering practice, and some have language difficulties . . . . Foreign-born graduates may not be optimum for engineering faculty positions (1981, pp. 63-64).

And Betty Vetter, executive director of the Scientific Manpower Commission, states that among non-resident aliens "who will remain in the U.S. after completing the doctorate, many may be less fluent in English than is desirable for teaching undergraduate engineering students" (Vetter, 1982, pp. 12-13).

In sum, not only does the large enrollment of foreign students limit the enrollment opportunities of American students, the high proportion of foreign students that remain in the U.S. appears to be contrary to the purposes of international education ("Foreigners Snap Up the High-Tech Jobs," 1981, p. F-3). Extensive enrollment of foreign students will not solve the nation's problem of losing its world leadership position in technology to other industrialized nations nor its problem of insufficient faculty for technological programs. Both State and institutional policy makers should review the enrollments of foreign students in the public segments together with increased stipends for domestic students in planning future enrollments, particularly at the graduate level.

IMPROVING TEACHING AND RESEARCH CONDITIONS

Both the University of California and the California State University have this year inaugurated revised salary schedules in engineering as well as business in order to attract qualified scholars to unfilled full-time faculty positions, but as noted in Chapter Three, even these new salary schedules are not fully competitive with beginning industrial salaries for the better new engineering Ph.D.s.

For this year, the Regents and the Trustees appear to have adopted the most competitive schedule possible under limited circumstances, but in cooperation with the Legislature and the Governor they should initiate long-range corrective measures for engineering salaries in order to increase their proportion of full-time faculty and particularly of full-time women, ethnic minority, and native-born faculty.

Beyond improved salaries, institutional administrators should be alert to two other facets of faculty life that require attention. One is the extent of regulation, particularly regarding reporting requirements, that increasingly permeate professorial as well as administrative activities, largely from federal sources but also from State and institutional offices. The other is the increasing threat of federal controls over research findings and scholarly communication.

CONTROLLING TECHNICAL INFORMATION

As America continues to slip in the world marketplace and American companies lose out to foreign competitors at home, the pressure for government controls on technical information has grown. In 1976, a study conducted by the Defense Science Board concluded that the United States was losing its technological and economic lead over adversaries by giving them expertise critical to the production of advanced technological devices, and it recommended stricter federal controls on the flow of technical information (Wallich, 1982, p. 69). Last year, several federal agencies imposed curbs on certain technical information exchanges and the Department of Defense proposed restrictions on research carried out under its Very High Speed Integrated Circuits (VHSIC) program:

> In the case of basic research supported by the VHSIC program, although such research and its results are not generally controlled, it is the preference of the Program Office that only U.S. citizens and immigrant aliens who have declared their intention of becoming citizens participate. Where this preference cannot be accommodated, the contractor should be directed to the Program Office for resolution (Gray, 1982, p. 67; underlining added).

At the January 1982 meeting of the American Association for the Advancement of Science, CIA officials told engineers and scientists that they must control the export of technical information voluntarily or face legislative action that will "slam shut" the information door. In February, Senator Jackson of Washington called for increased controls on technical information and scientific exchanges. Federal officials maintain that the "leaking" of technical materials and ideas to other nations impairs national security both by diminishing the ability of the U.S. to compete commercially and by reducing the country's edge in armaments.

Gordon E. Moore, chairman of Intel Corporation, in discussing the complexity of the security and scientific issues, states, "There is a very real issue concerning the flow of information out of the United States. Universities are involved in technologies that are important to the U.S. both strategically and commercially. While some defense proposals go way overboard, many universities are living in a naive world" ("How Much Secrecy is Needed in the Lab?," 1982, p. 34). Other industrial executives also feel that academics have been in a privileged position for a long time. Arthur Stern, president of Magnavox Advanced Products and Systems, says, "frankly, I resent the blindness of academia, which goes by rules made in the nineteenth century." And Tom Christiansen, manager of international trade relations for Hewlett-Packard, says, "there has been a dual standard. Universities have had relatively little government control of information, while companies have had a great deal" (Wallich, 1982, p. 71).

During World War II, the nation's universities undertook both basic and applied classified research that led to radar, fire control systems, navigational aids, jet-aircraft design, and nuclear weapons. They accepted secrecy as essential to winning the war. However, after several decades of peace, many university leaders now strongly oppose the new efforts of government officials to control the flow of technology beyond the country's borders.

As Paul Gray of MIT has said about the proposed limits on VHSIC research, "[the government] proposed restrictions--applicable even to basic research--that disregard both the international character of U.S. universities and the difficulties such institutions would have in confining participation in and access to research to U.S. citizens and immigrant aliens" (p. 67).

Gray has joined with the presidents of four other universities that are heavily involved in advanced technological research--California Institute of Technology, Cornell, Stanford, and the University of California--to express concern to the Secretaries of Commerce, Defense, and State and requested clarification concerning this and other attempts to apply arms and export regulations to university research. Beside the issues of academic freedom and open research, questions involve the impact of research restrictions on the graduate education and employment of foreign nationals, scholarly exchange programs, and universities' efforts to recruit the most able doctoral recipients into the faculty.

These questions are being addressed by two groups: (1) a National Academy of Sciences--National Academy of Engineering panel, chaired by Dale R. Corson, president emeritus of Cornell University, to study the impact of national security regulations on the conduct of unclassified research; and (2) the DOD/University Forum, co-chaired by Richard D. DeLauer, Defense Undersecretary for Research and Engineering, and Donald Kennedy, president of Stanford, which will give high priority to the issue of control of unclassified research. A great deal of public discussion will take place before any regulations are developed.

UPDATING EQUIPMENT AND FACILITIES

It is clear that substantial amounts of money will be needed to modernize engineering laboratories in California's universities. Data from the University of California indicates that approximately $7.5 million per year will be needed for the next several years to replace obsolete equipment in engineering and computer science alone, out of an annual total need of $15 million. Modern state-of-the-art equipment will also be necessary in many areas at an estimated cost of $11.8 million in order to offer new courses in new technologies.

The equipment problem in the State University is even more severe. A long-range plan that provides it with some $12 million per year for at least ten years will be necessary to bring its instructional programs up to a minimum level of content and laboratory skills.

In both systems, some engineering facilities need extensive remodeling, and based upon campus responses to the Commission's questionnaire and capital outlay budgets, it appears that among all campuses, the University of California at Santa Barbara should be given priority in the construction of additional engineering facilities. The major reason why enrollments are forced to be limited at Santa Barbara is lack of facilities. Santa Barbara has only 55 percent of the space that would be called for by State facility standards applied to their present enrollments.

IMPROVING STUDENT PREPARATION

The United States now ranks fourth in scientific literacy behind the Soviet Union, Germany, and Japan. Soviet students begin studying algebra and geometry in grades 6 and 7, add trigonometry in grades 8 through 10, and calculus in high school, and all high school graduates complete five years of physics, four years of chemistry and up to four years of biology.

German students begin studying science in the third grade, with biology, chemistry, physics, and an introduction to geometry added in grade 5, algebra introduced in grade 7, and algebraic functions and differential calculus taught in grade 11. By the end of grade 13, they have studied integral calculus, statistics, probability, and vector analysis.

Japanese students spend one-fourth of grades 7 to 9 in mathematics and science, with trigonometry introduced in grade 9, and calculus and statistics offered in high school. Indeed most other major industrialized nations require science and mathematics literacy for all students rather than only those planning careers in science or mathematics, on the basis that all citizens are increasingly called on to make technological decisions and understand the implications of scientific and technological advances.

A long-range solution to America's problem of maintaining leadership in world industry calls for similar attention to science and mathematics in elementary and secondary school curricula and for restructuring teacher education and employment. In California, Governor Brown's "Investment in People" initiative proposes to allocate $18.6 million to the public schools for staff development in mathematics and science and for replacing out-of-date textbooks in these fields. These steps are desirable, but also needed are better qualified teachers and better teaching equipment. Counselors should encourage mathematics and science literacy among all students but particularly among minorities and women. If more adequate salaries are not possible for all teachers, the Legislature should consider permitting differential salaries or bonuses for mathematics and science teachers in the schools, just as the University and State University have now done for faculty in engineering and business.

INCREASING SUPPORT

Several sources of funds besides State support may help enhance engineering and computer science education in California and elsewhere. Deans William M. Kays of Stanford and Lionel Baldwin of Colorado State University have proposed that industry and government pay to each university from which they hire an engineering alumnus an amount such as $2,000 for a bachelor's degree holder, $3,000 for a master's degree recipient, and $5,000 for a doctorate. This concept has been proposed at various times by other individuals since the 1950s. Each time, however, it has been rejected because of the difficulty of establishing payment schedules to each of a variety of institutions and of differentiating payments by discipline.

The National Society of Professional Engineers (NSPE) has suggested that the federal government provide funds of up to $90 million per year to engineering colleges for federal fellowships and $100 million per year over the next ten years for major equipment purchases, with the fellowship program providing increasing stipends to Ph.D. candidates of $11,500, $13,500, and $15,500 during the three years of their Ph.D. program, plus a $1,500 annual matching grant to the department in which the student is enrolled. The fellowship program, which has been endorsed by the American Society for Engineering Education (ASEE) as a means to fill faculty ranks, would aim at producing 1,000 new engineering Ph.D.s per year. Its costs are estimated at $29.9 million for the first year and $59.9 million for the second with steady-state costs thereafter of $89.6 million annually. NSPE and ASEE argue that the problems of engineering education have grown to such an extent that only the federal government has the resources for a national solution. In view of past experiences with federal support to higher education, this proposal represents a feasible role for the federal government if the program were administered by the states. Yet present federal priorities point to dim prospects for the program.

James Hunt, Governor of North Carolina, has proposed that the center of gravity for technological innovation shift from the federal government to state governments. He contends:

> Of the 184 research universities of this nation, 119 are public institutions, most of which are supported by state governments. Elementary and secondary educational systems are the responsibility of state and local governments, who (regardless of action by the federal government) must take the lead if significant improvements are to be achieved. State and local governments are the prime points of contact with the many aspects of economic activity that entails industry-government interaction. Finally, people are essential in technological innovation, and people can more easily relate to state and local government than to distant federal agencies (1982).

Chapter Six of this report highlighted some of the high-technology incentives initiated by other states besides California. California is one of a few states that can provide the infusion of funds to its universities necessary to meet the technological challenge that faces its industry. Even if the federal government reverses its present retreat from the support of education, State government in California should join with industry to invest in its engineering schools and related technological education programs. The State has the fundamental responsibility for these schools as it has for all of education.

A decline in quality haunts many engineering schools in California as well as elsewhere in the nation. Unfilled full-time faculty positions, heavy teaching and advising loads, inadequate laboratory equipment, insufficient student preparation and other problems are affecting the quality of engineering graduates on which the State's economy and the nation's well-being depend. Without more support than proposed in the "Investment in People" program, these problems will remain beyond their control. California's engineering schools are even now producing only a fraction of the number of graduates that the State's economy needs, due to financial restrictions and impacted admissions. If they are not to extend themselves beyond their capability of providing quality instruction, they will require major new support; otherwise the number of their students should be reduced in order to preserve quality.

REFERENCES

Accreditation Board for Engineering and Technology. *Accredited Programs Leading to Degrees in Engineering, 1980*. New York: The Board, 1980.

American Council on Education. *Higher Education and National Affairs*, 31:3 (February 5, 1982).

American Electronics Association. *Planting the Engineering Seed Corn*. Palo Alto: The Association, August 1981a.

American Electronics Association. *Technical Employment Projections, 1981-1983-1985*. Palo Alto: The Association, May 1981b.

Atelsek, Frank J., and Gomberg, Irene L. *Recruitment and Retention of Full-Time Engineering Faculty, Fall 1980*. Higher Education Panel Report No. 52. Washington, D.C.: American Council on Education, October 1981.

Batton, Frank. "Reaching a Higher Standard of Living." New York: The New York Stock Exchange, January 1979.

Booth, Howard. *Equipment Replacement Program*. Berkeley: University of California, Office of Budgetary Planning, April 1975.

Bromley, D. Allan. "The Fate of the Seed Corn," Editorial, *Science* (American Association for the Advancement of Science, Washington, D.C.), 213:4504, July 10, 1981.

Bureau of Labor Statistics, U.S. Department of Labor. *Bulletin 2052*, September 1980.

California Postsecondary Education Commission. *Equal Educational Opportunity in California Postsecondary Education, Part IV*. Commission Report 82-19. Sacramento: The Commission, April 1982.

California Postsecondary Education Commission. *Postsecondary Education in California: 1981 Information Digest*. Commission Report 81-20. Sacramento: The Commission, 1981.

California State Department of Education. *Curriculum Review Handbook*, Second Draft. Sacramento: The Department, October 1981.

"California Students Avoiding the Tough Subjects." *Engineering Education News* (American Society for Engineering Education, Washington, D.C.), 7:3, September 1980, 1.

Castillo, Cathy. "Area Schools Called Deficient in High-Technology Education," San Jose Mercury, August 5, 1981.

College Placement Council, Inc. CPC Salary Survey. Formal Report No. 2, March 1982. Bethlehem, PA: The Council.

"Crisis in Engineering Education." Civil Engineering (American Society for Civil Engineering, Washington, D.C.), March 1981, 63-65.

Curriculum Review Handbook, Second Draft. Sacramento: California State Department of Education, October 1981.

David, E. E., Jr. "National Engineering Action Conference," Editorial, Science (American Association for the Advancement of Science, Washington, D.C.), 216:4545, April 30, 1982, 465.

"Decline in Technical Demand Index Expected to Continue." IEEE Spectrum (The Institute of Electrical and Electronic Engineers, New York), 19:5, May 1982, 22.

Deutsch, Shea & Evans, Inc. New High Technology Recruitment Index. New York: 1979.

Doigan, Paul. "Engineering and Technology Degrees, 1981," Engineering Education (American Society for Engineering Education, Washington, D.C.), 72:7, April 1982, 704-709.

Drucker, Daniel C. "The Crisis in Engineering Education." Washington, D.C.: American Association of Engineering Societies, April 22, 1981.

Education Roundtable. "Engineering Education: Coping with the Crisis," IEEE Spectrum (The Institute of Electrical and Electronics Engineers, New York), 18:11, November 1981, 65-71.

Eisenberg, Elliot, and Galanti, Anthony V. "Why Engineers Leave Academia," Engineering Education (American Society for Engineering Education, Washington, D.C.), 71:7, April 1981, 700-704.

Employment Development Department, State of California. Projections of Employment by Industry and Occupation, 1980-85. Sacramento: The Department, September 1979.

"Engineer Shortage Called Threat to Security, Economy." The Institute, News Supplement to IEEE Spectrum (The Institute of Electrical and Electronics Engineers, New York), 6:1, January 1982, 6.

"Engineering Education: Coping with the Crisis." *IEEE Spectrum* (The Institute of Electrical and Electronic Engineers, New York), 18:11, November 1981, 65-71.

Engineering Education News. (American Society for Engineering Education, Washington, D.C.), 8:7, January 1982a.

Engineering Education News. (American Society for Engineering Education, Washington, D.C.), 8:9, March 1982b.

Engineering Education News. (American Society for Engineering Education, Washington, D.C.), 8:10, April 1982c.

"The Enrollment Boom Among Older Americans." *The Chronicle of Higher Education*, 22:11, May 4, 1981, 3.

"Fact-File: Engineers and Scientists at Colleges." *The Chronicle for Higher Education*, 24:9, April 28, 1982, 10.

"Falling State Revenues, Cuts in Payrolls Bring Hard Times to Public Institutions." *The Chronicle of Higher Education*, 23:22, February 10, 1982.

"Foreigners Snap Up The High-Tech Jobs." *New York Times*, July 5, 1981, p. F-13.

Glower, Donald D. "Civilization Beyond the '80s: Is There Hope for the U.S.?" *Engineering Education* (American Society for Engineering Education, Washington, D.C.), 72:5, February 1982, 389-393.

Gray, Paul E. "Technology Transfer at Issue: The Academic Viewpoint," *IEEE Spectrum* (The Institute of Electrical and Electronic Engineers, New York), 19:5, May 1982, 64-68.

Hansen, Arthur G. "Scientists, Engineers, and National Security: An Educational Perspective," *The Bridge* (National Academy of Engineering, Washington, D.C.), 11:1, Spring 1981, 20-24.

"How Much Secrecy is Needed in the Lab?" *Business Week*, March 29, 1982, pp. 34-35.

Hoy, John C., and Bernstein, Melvin H., editors. *Business and Academia: Partners in New England's Economic Renewal*. Hanover, N.H.: University Press of New England, 1981.

Hunt, James B. "State Involvement in Science and Technology," Editorial. *Science* (American Association for the Advancement of Science, Washington, D.C.), 216:4534, February 12, 1982.

IEEE Spectrum. New York: The Institute of Electrical and Electronics Engineers.

The Institute, News Supplement to *IEEE Spectrum* (The Institute of Electrical and Electronics Engineers, New York), 6:1, January 1982, 1, 7.

Investment in Economic Strength. Sacramento: California State Business, Transportation, and Housing Agency; Department of Economic and Business Development; Department of Industrial Relations; and Office of Planning and Research, March 1981.

Jones, Russel C. "Crisis in Engineering Education," *Civil Engineering* (American Society for Civil Engineering), March 1981, 63-65.

Kahne, Stephen. "A Crisis in Electrical Engineering Manpower," *IEEE Spectrum* (The Institute of Electrical and Electronic Engineers, New York), 18:6, June 1981, 50-52.

"Keeping Track on 'The Engineering Shortage.'" *The Boston Globe*, December 15, 1981.

Kemper, John D. "A National Survey to Determine the Shortage of Engineering Faculty Candidates," Unpublished paper, University of California, Davis, 1980.

Klein, Sarah E. *Testimony to the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U.S. House of Representatives*, February 25, 1982.

Kreinberg, Nancy. "1000 Teachers Later: Women, Mathematics, and the Components of Change," *Public Affairs Report* (Institute of Governmental Studies, University of California, Berkeley), 22:4, August 1981.

Landis, Fred. "How Many Engineers Will Graduate During the Eighties?" *Engineering Education* (American Society for Engineering Education, Washington, D.C.), 7:8, May 1981, 784-788.

Middleton, Lorenzo. "Congress Weighs Bill to Force Aliens to Leave U.S. After Graduation," *The Chronicle of Higher Education*, 24:12, May 19, 1982, 1, 18.

National Academy of Engineering. *Academe/Industry/Government: Interaction in Engineering Education*. Washington, D.C.: The Academy, 1981.

National Academy of Engineering. Roundtable on Education and Utilization of the Engineer, 1980-2000. *The Bridge* (National Academy of Engineering, Washington, D.C.), 11:3, Fall 1981, 5-8.

National Council of Teachers of Mathematics. *Press Release*. Washington, D.C.: The Council, October 19, 1981.

"National Engineering Action Conference." *Engineering Education News* (American Society for Engineering Education, Washington D.C.), 8:10, April 1982, 1, 7.

National Science Foundation. *Science Resources Studies Highlights*, November 2, 1981.

National Science Foundation and U.S. Department of Education. *Science and Engineering Education for the 1980's and Beyond*. Washington, D.C.: U.S. Government Printing Office, October 1980.

New York Times. "National Recruitment Survey" Section, October 11, 1981.

"Now, a Brain Drain From the Frost Belt." *U.S. News and World Report*, September 21, 1981, 87-89.

Perkins, Courtland D. "The Growing National Crisis in Engineering Education," *The Bridge* (National Academy of Engineering, Washington, D.C.), 11:1, Spring 1981, 1-4.

Peterson, Ivor. "A Great University Retrenches," *This World*, April 18, 1982, 25.

Pettit, Joseph M. "Engineering Supply and Demand in the U.S.--A Current Crisis," *The Bridge* (National Academy of Engineering, Washington, D.C.), 11:3, Fall 1981, 26-29.

"Quality is Main Problem in Engineering Crisis." *IEEE Spectrum* (The Institute of Electrical and Electronic Engineers, New York), 19:5, May 1982, 32.

Ramo, Simon. *Newsweek*, August 14, 1981, 71E.

"Reality of Manpower Crisis Debated at Careers Meeting." *The Institute*, News Supplement to *IEEE Spectrum* (The Institute of Electrical and Electronics Engineers, New York), 6:1, January 1982, 7.

Samuelson, Robert J. "A New Engineering Boom Creates Campus Problems," *Los Angeles Times*, December 15, 1981.

Savage, David G. "Math, Science Teacher Shortage Grows," *Los Angeles Times*, January 7, 1982.

"Science Advisor Tackles Problems that Face Engineering Education." The Institute, News Supplement to IEEE Spectrum (The Institute of Electrical and Electronics Engineers, New York), 6:1, January 1982, 1, 6.

Sirotkin, Phillip. "State, Higher Education, and Industry Cooperation to Expand High Technology Human Resources in the West: A Prospectus." Boulder: Western Interstate Commission for Higher Education, February 1982.

"Statewide High School Standards Urged." The Sacramento Bee, April 29, 1982, A18.

"Surge in Engineering Enrollments Begins to Ease Industry's Shortages but Stirs Trouble at Colleges." The Wall Street Journal, August 20, 1981.

Task Force on Engineering Education, National Academy of Engineering. "Issues in Engineering Education, A Framework for Analysis." Washington, D.C.: The Academy, April 1980.

"Tomorrow - Newsgram." U.S. News and World Report, 92:18, May 10, 1982, 18.

"Two Surveys Find Job Opportunities Good for Engineers." The Chronicle for Higher Education, 23:17, January 6, 1982, 10.

Vetter, Betty M. Supply and Demand for Scientists and Engineers. Second Edition. Washington, D.C.: Scientific Manpower Commission, January 1982.

Wallich, Paul. "Technology Transfer at Issue: The Industry Viewpoint," IEEE Spectrum (The Institute of Electrical and Electronic Engineers, New York), 19:5, May 1982, 69-73.

Western Interstate Commission for Higher Education. "Can Higher Education Meet the Need for Technical Manpower," WICHE Reports, 26:2, Summer 1981, 11-13.

What are the Needs in Precollege Science, Mathematics, and Social Science Education? Views from the Field. Washington, D.C.: National Science Foundation, 1980.

Willenbrock, F. Karl. "United States and Technological Preeminence," Editorial, Science. (American Association for the Advancement of Science, Washington, D.C.), 213:4514, September 18, 1981.